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Hush House Induced Vibrations at the Arkansas Air National Guard Facility, Fort Smith, Arkansas

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JAMES C. BATTIS



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EARTH SCIENCES DIVISION

PROJECT 7600

AIR FORCE GEOPHYSICS LABORATORY

HANSCOM AFB, MA 01731

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HENRY A. OSSING, Chief
Solid Earth Geophysics Branch


DONALD H. ECKHARDT
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Hush House Induced Vibrations at the Arkansas Air National Guard Facility, Fort Smith, Arkansas

1. INTRODUCTION

1.1 Background

The T-10 jet engine ground run-up noise suppressor, or Hush House, (Figure 1), was designed to reduce the audible impact of necessary jet engine testing on the surrounding community and to allow siting of the test function closer to the maintenance operations that it supports. At least in part, the noise suppression characteristic of the Hush House is achieved by the transfer of energy from the audible (> 20 Hz) to the infrasonic (< 20 Hz) range. At some sites these lower frequency emissions have had deleterious effects on the vibro-acoustic environments in nearby buildings. In one instance, sufficiently intense disturbances were reported to raise questions concerning both the structural safety and health of the occupants.¹

In May 1984, the Air Force Geophysics Laboratory (AFGL) was requested by Air Force Logistics Command (AFLC) to assist in the development of siting criteria to mitigate these problems for the T-10 Hush House. At that time AFGL/LWH recommended that AFLC consider the development and application of a site-specific vibro-acoustic forecast method based on techniques previously developed by AFGL

(Received for publication 29 October 1987)

1. Personal Communications, Maj. William Ponder, USAFR, October 1984.

to support Space Shuttle operations at Vandenberg AFB, California.^{2,3} It was felt that this technique could be modified for use in Hush House site selection and to minimize post-construction disturbances on operations in nearby structures.

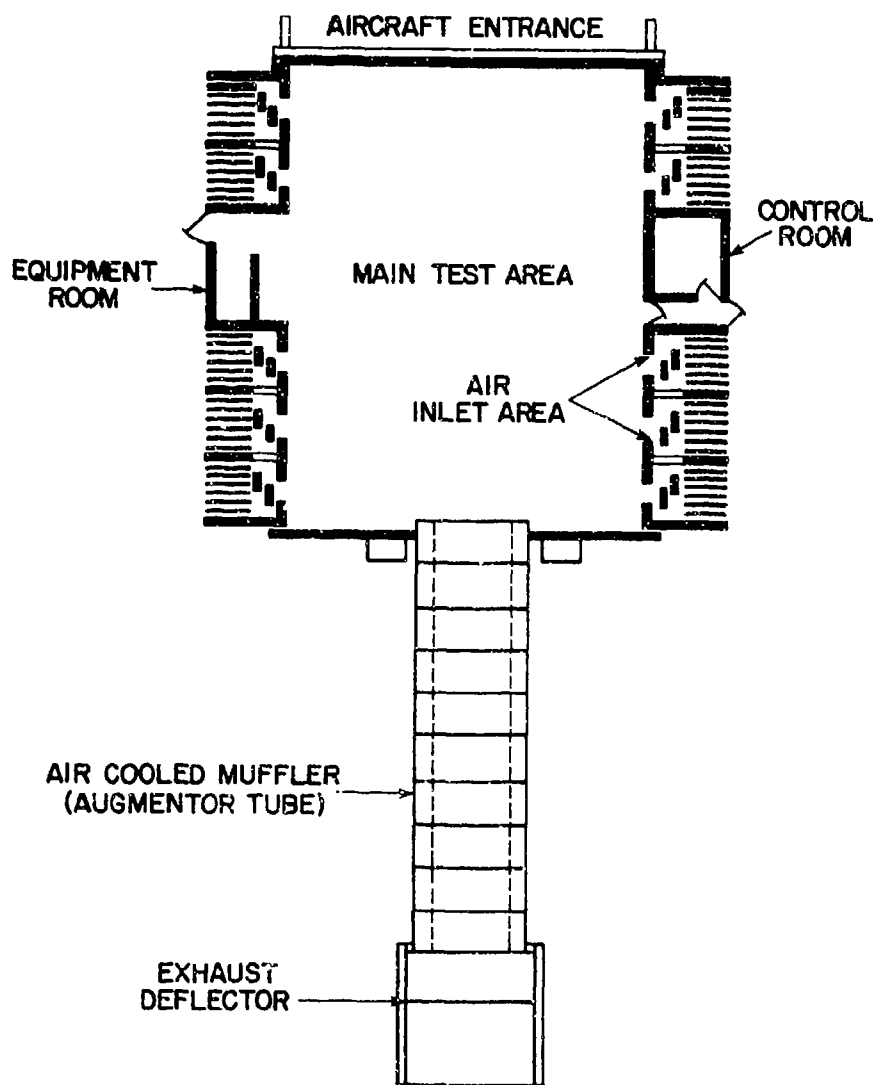


Figure 1. Plan View of the T-10 Hush House

2. Crowley, F.A., and Hartnett, E.B. (1984) Vibro-Acoustic Forecast for Space Shuttle Launches at VAFB, The Payload Changeout Room and the Administration Building, AFGL-TR-84-0322, ADA 156944, Hanscom AFB, MA.
3. Battis, J.C. (1985) Vibro-Acoustic Forecasts for STS Launches at V23, Vandenberg AFB: Results Summary and the Payload Preparation Room, AFGL-TR-85-0133, ADA 162192, Hanscom AFB, MA

The effort to refine this methodology for application to the Hush House problem started with a preliminary field study conducted at Luke AFB, Arizona in September 1984. This study demonstrated several facts relevant to the Hush House siting problem. First, the dominant cause of induced vibro-acoustics in structures near the Hush House is airborne infrasonics.⁴ Second, the propagation characteristics of the Hush House infrasonic emissions can largely be explained as spherical propagation from an azimuthally dependent source located 10 m above the exhaust deflector at the end of the augmentor tube (Figure 1).⁵ Finally, and as was expected, the response of the impacted structures depends not only on range from the Hush House, but also on the relative orientations of the infrasonic noise source, that is, the Hush House, and the impacted structure.⁴ Using methods developed by AFGL, it was shown that well over 90 percent of the observed energy in the Hush House induced vibrations can be forecast given adequate knowledge of the source. Taken together with other findings from this work, the Luke study supported the feasibility of forecasting, prior to construction, the environment in neighboring structures that would be excited by Hush House operations.

Analysis of data taken at Luke AFB also motivated the development of a hypothetical source model for Hush House acoustics. This working hypothesis is discussed in Appendix A. Basically, the model assumes that the acoustic emissions are generated by turbulence associated with the air intakes and exhaust of the Hush House. The characteristic spectral form for the emissions is a bell shaped curve, peaking near 15 Hz, due to the exhaust jet, with a weaker secondary lobe at about 5 Hz believed to be due to the intake jets. For a given Hush House design, the locations of these peaks and the spectral levels will vary with the velocity of the exhaust and intake air. These, in turn, are functions of the size and power level of the engine being operated in the Hush House.

1.2 Hush House Siting Criteria

At present, siting guidelines for the T-10 are based on zones of exclusion around the Hush House within which the siting of specified structures or activities are restricted. One example of this type of criterion is given in Table 1.⁶

4. Battis, J.C., and Crowley, F.A. (1986) Forecasting Hush House Induced Vibro-Acoustics, Proceedings of NATO-CCMS, Conference on Aircraft Noise in a Modern Society, NATO No. 161, Mittenwald, Germany.
5. Beaupre, J. T., and Crowley, F.A. (1987) Hush House Infrasonic and Seismic Emissions Produced by F-100 Engine Tests at Luke AFB, Arizona, Scientific Report No. 1, Weston Observatory, Boston College, Weston, MA.
6. ALC/MMEDT (1983) Procedures for Identifying and Justifying Base Requirements for Aircraft Turbine Engine Ground Run-up Noise Suppressors, T.O. 00-25-237, Kelly AFB, TX.

These criteria, being generalized for wide application, must balance two conflicting issues, maximizing land use at all sites and minimizing the incidence of significant adverse impact. On one hand, to insure adequacy in a worst case scenario, the zones of exclusion can be made extremely large, resulting in poor land use in most applications. Alternatively, the zones can be reduced in size to represent more "typical" conditions with the acceptance of a higher likelihood of adverse impacts requiring post-construction corrective action and resulting increase in cost. On the positive side, this type of criteria can be made easily understandable by the end user and is simple to apply.

Table 1. Zone of Exclusion Type Siting Guidelines for T-10 Hush House⁶

Facility/Activity	Distance (m/ft)*	Criteria Basis
Unoccupied Facilities	5/16, as measured from any exterior point on Hush House 33/100, as measured from exhaust tube entrance.	No risk of architectural damage from vibration.
Workshop (full-time occupancy)	49/150	Noise and vibration.
Pre-engineered Buildings	115/350	Exterior panels exhibit considerable vibration.
Office	164/500	Noise
Vibration Sensitive Equipment (for example, optical microscopes, photo interpretation light tables).	328/1000	Vibration
Housing (less than four stories)	328/1000	Noise
Housing (more than three stories)	492/1500	Noise

NOTE: Distances are for minimum personal complaints.

* Radial distance as measured from both ends of the exhaust tube. The two semicircles described by the arcs, connected by straight lines at circumferences, form distance envelope.

NOTE: Above criteria developed from noise and vibration surveys conducted at 149th ANG, SA-ALC.

The intrinsic balance discussed above must result from the fact that a zone of exclusion type criterion is unable to account for any of the site-specific elements of the problem, primarily the site dependent effects on acoustic propagation and the unique response characteristics of potentially impacted structures. The last of these complications should be obvious to anyone familiar with structural dynamics. A useful example of the former problem has been documented at the Shuttle launch complex at Vandenberg Air Force Base (SLC-6).² Due to multipathing (echoes) of the acoustic signal at the Vandenberg complex, frequency dependent loads on structures are as much as 14 dB or five times greater than would be anticipated at the same distance from a source in an open setting, the conditions found at the Shuttle facility at Kennedy Space Center (KSC). In other words, zones of exclusion based on data from KSC would greatly underestimate the vibro-acoustic effects anticipated at the Vandenberg launch complex.

1.3 Fort Smith, Arkansas Field Study

The Arkansas Air National Guard (ANG) facility at Fort Smith provided a case with which to measure the value of existing Hush House siting criteria. At present, the ANG maintains a T-10 Hush House for testing of F-4 Phantoms. It is intended that this ANG unit will upgrade to F-16 aircraft in the near future.⁷ An existing building, the Avionics Building, could be modified to accommodate the F-16 avionics test equipment. However, based on existing Hush House siting criteria, a new facility for this equipment should be constructed at a distance of over 328 meters from the Hush House as the test equipment is considered motion sensitive. The cost of this new construction would exceed the cost of modifying the existing facility.

At the request of ANG, AFGL conducted a vibro-acoustic survey at the Fort Smith facility to measure vibration levels in existing structures due to Hush House operations. This report provides the results of that survey and the implications of this effort towards the development of more efficient criteria for siting infrasonic noise sources such as the Hush House.

7. Personal Communications, Lt. Col. Steve Core, Arkansas ANG, October 1986.

2. SITE DESCRIPTION

2.1 Location

Fort Smith, Arkansas, is located in the northwest corner of the state at the juncture of the Arkansas and Poteau Rivers. The ANG facility is located on a flat plain trending essentially north-south, a former river course. Just to the west of the ANG facility, a rise marks the edge of the river valley. On the east, the facility is bounded by the municipal airport, also in the river valley. The eastern edge of the valley is well to the east of the site. The topographic and geologic settings of the site do not appear to play a significant role in the results of this study.

2.2 ANG Facilities

The ANG facility is composed primarily of one and two story structures of masonry and steel frame construction, and hangar facilities. In addition, the site has several steel frame, pre-engineered structures. A section of the ANG compound is shown in Figure 2. The primary buildings of interest in this study are the Avionics Building and Building 221 (an aircraft radar test facility) and the T-10 Hush House, all indicated in Figure 2.

The Avionics Building is a one-story structure of steel frame and brick construction located approximately 260 meters from the Hush House exhaust deflector. Although irregular in form, dimensions of the structure are roughly 50 by 25 meters. The building is broken into office, workshop, and warehouse space. The warehouse section of the building is a high bay with a height greater than the other sections of the building. As this facility is a potential site of the F-16 avionics test equipment, the motions of concern at this location are those of the concrete slab floor on which the avionics test benches would be mounted. It should be noted that this structure lies well within the 328-meter zone of exclusion for motion sensitive operations.

Building 221 is a pre-engineered, steel frame, sheet metal sided, hangar type structure located approximately 82 meters from the exhaust deflector. The dimensions of this structure are about 26 by 16 meters by 10 meters high and consists essentially of a single aircraft bay. The short walls are cut by hangar doors on both ends. This site had exhibited vibration problems during F-4 Hush House operations, including loosened panel screws and obvious vibrations of structure. It was requested that the safety of the structure be evaluated for F-16 Hush House operations.

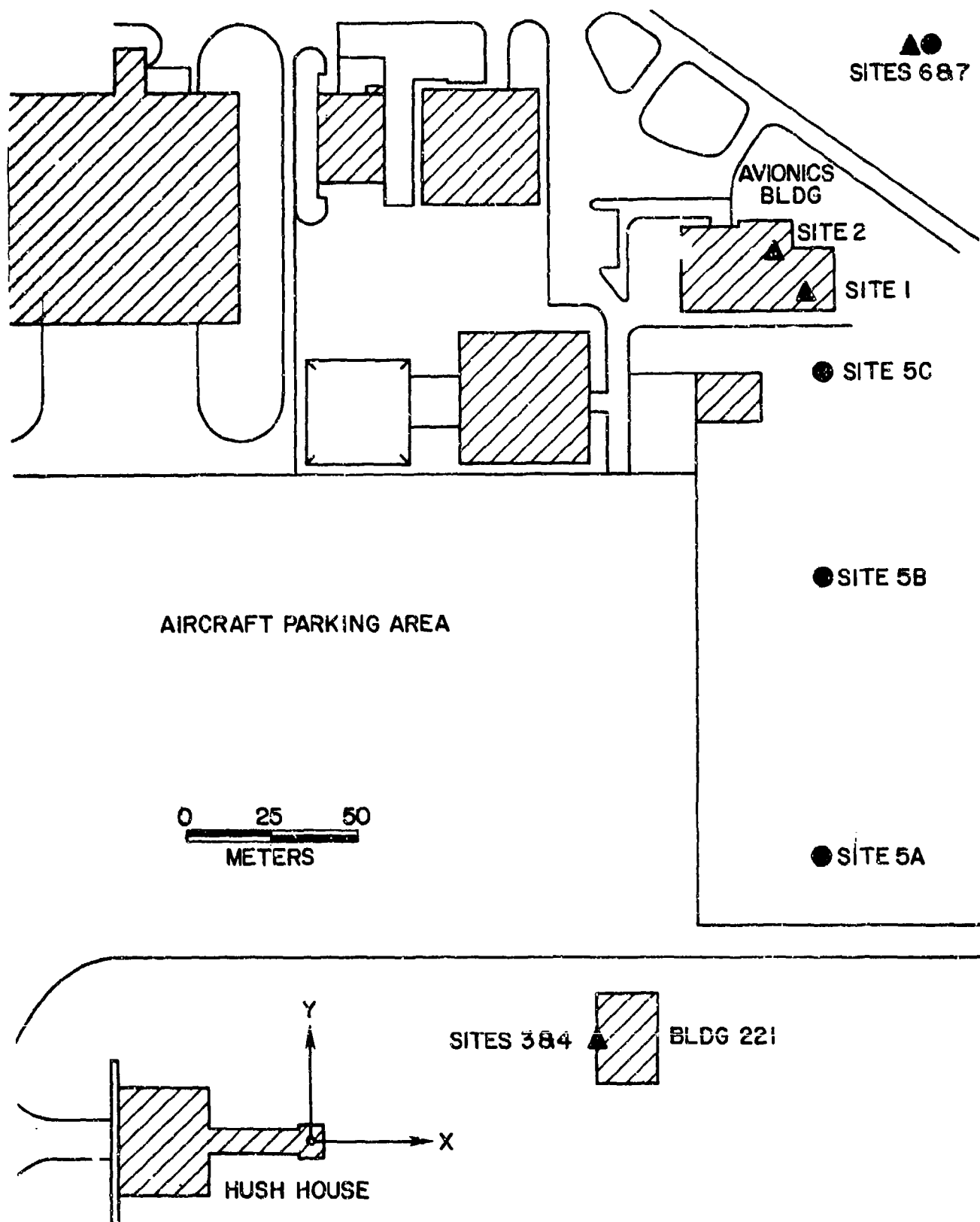


Figure 2. Plan View of the ANG Facility at Fort Smith Smith, Arkansas
With Sensor Locations Indicated

As noted previously, based on ANG interpretation of the Hush House siting guidelines, a new structure is required to house the F-16 support equipment. The land available for this purpose is located to the north of the Avionics Building as indicated in Figure 2. It was also requested that noise studies be conducted at this location to determine its suitability for the proposed construction. In addition to Hush House operations, the potential effect on the vibration environment at this site because of traffic on Interstate Highway I-540 was of concern.

3. VIBRO-ACOUSTIC MEASUREMENT SYSTEM

3.1 Data Measurement System

Instrumentation used to monitor the vibro-acoustic environment at the Fort Smith ANG site consisted of Terra Technology Inc. DCS-302 digital data recorders with sensor elements consisting of either Geo Space Corp. Hall-Sears HS-10-1B or Dyneer S-6000 velocity transducers, or DJ Instruments MLR differential pressure transducers. These systems provide responses with an essentially flat measurement window from 1 to 30 Hz. Typical examples of the system response functions for a vibration and a pressure measurements are shown in Figures 3 and 4.

In-situ calibrations were performed on the velocity transducers before and after the test sequence by applying a known current to the calibration coils of the instruments. This is the equivalent of applying a known force to the mass of the seismometers. Calibrations of the pressure transducers and the digital recorder units were conducted in the laboratory either before or after the field tests. The instrument constants of these units have been found to be quite stable.

The Terra-Technology DCS-302 digital data recorders provide signal amplification with automatic gain ranging, A/D conversion and anti-alias filtering. Four gains are available with nominal levels of x10, x50, x250, and x1000. Given the sensor sensitivities, this provides approximate dynamic ranges of 5×10^{-8} to 3×10^{-3} m/sec in velocity and 0.01 to 3500 Pa for pressure. The exact dynamic range at each site is a function of the particular sensors and recorders used as well as ambient noise conditions.

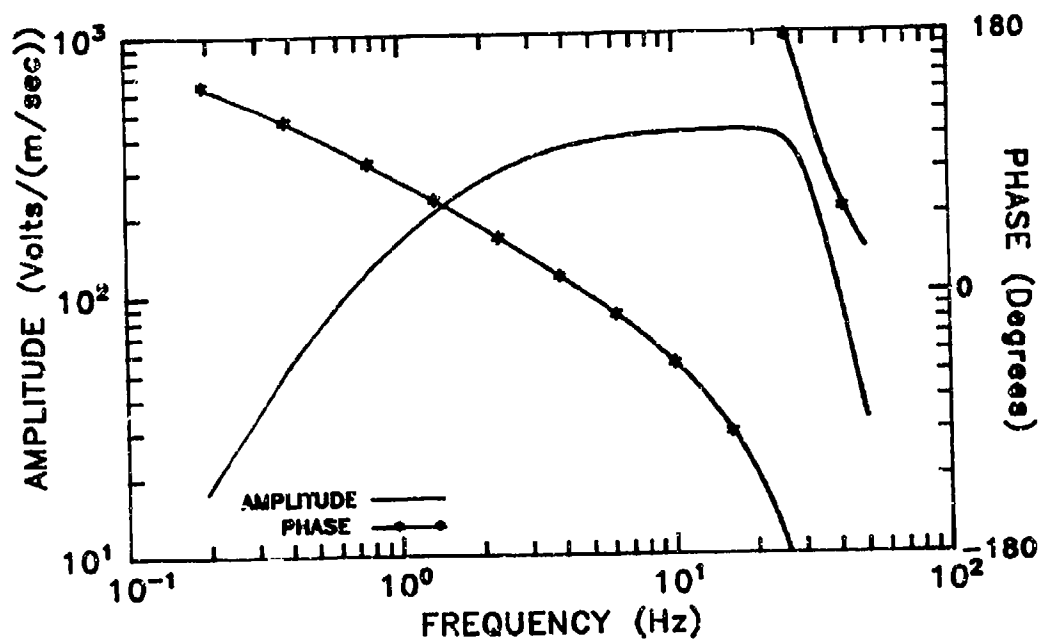


Figure 3. Typical Measurement System Response for a Velocity Transducer

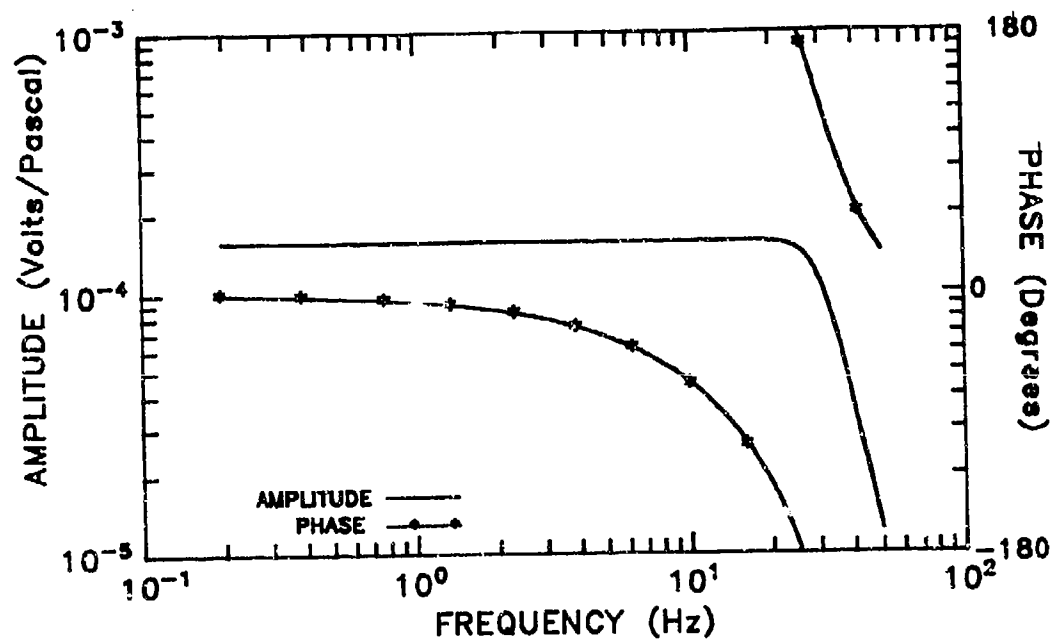


Figure 4. Typical Measurement System Response Curve for a Pressure Transducer

3.2 Instrumentation Locations

During the test sequence nine locations were monitored for either pressure or vibration. Once installed, the instruments at each site were left undisturbed throughout the test period. In addition, one site was occupied for a short period to monitor highway generated noise. The locations of the measurement points are shown in Figure 2. Additionally, Table 2 provides information on the sites and sensors.

Pressure measurements were made at four locations, three to the north of the main aircraft parking area, sites 5A through 5C and one at the approximate location of the proposed avionics building, site 6. A velocity transducer, site 7, was collocated with site 6.

The existing Avionics Building was instrumented at two locations. First, vibration data was taken at the footing of a column in the warehouse section of the building, site 1. These sensors monitor the largest single open area in the structure with the highest roof line and exposed surface area directed towards the Hush House. It was anticipated to be the most responsive section of the building to Hush House infrasonic emissions. Site 2 was located within the workshop area of the building at the base of the Inertial Measurement Unit (IMU) pedestal. This site was selected to provide a comparison of the relative strength of the Hush House induced vibrations against a typical working noise environment.

Vibration sensors at sites 3 and 4 were located in Building 221, the radar test hangar. Site 3 was placed on the foundation slab near the footing of the center column on the wall facing the Hush House. Site 4 was located vertically above site 3 at the first column-beam connection, approximately 4.6 meters above the floor, halfway up the side wall. It will be significant to note that both of these sensors were somewhat offset from the column due to the physical structure in the vicinity of the joint.

Finally, site 8 is located near the edge of the ANG property and in line with the closest approach of Interstate I-540 to the proposed site of a new avionics building. This site was occupied only for the highway noise study when velocity measurements were made both here and at site 7. The site is not shown in Figure 2 but it is located off the plan somewhat north of a radial line through the exhaust deflector of the Hush House and sites 6 and 7.

For all sites involving velocity transducers, three components of motion, vertical and two horizontal axes, were measured. The horizontal components were aligned such that one component, the radial, was directed toward the assumed dominant infrasonic noise source, the exhaust deflector of the Hush House. The second horizontal component was rotated 90 degrees from the radial and is designated as the transverse component throughout this report.

Table 2. Site Data for the Fort Smith Noise Survey

SITE	RECORDER NO	CHANNEL NO	ORIENT- ATION	SEISMOMETER S/N	LOCATION	X FT/M	Y FT/M	R FT/M	AZIM (DEG)	SENSITIVITY (V/M/S)	Fo (Hz)	Bo
1	312	1 2 3	VERT RADI TRAN	HS-104553 HS-104542 HS-104705	Avionics Building Warehouse Section Column Footing	430 131	745 227	860 262	120	424.27 497.53 529.54	0.89 1.06 1.25	1.473 1.256 1.058
2	278	1 2 3	RADI TRAN VERT	DYN-9324	Avionics Building IMU Pedestal	406 124	778 237	878 267	118	171.55 156.63 181.35	1.94 2.04 2.34	0.401 0.354 0.336
3	320	1 2 3	RADI TRAN VERT	DYN-9325	Bldg 221 - ground Center Column Hush House side	254 77	89 27	269 82	151	198.42 185.27 180.06	2.02 2.04 2.41	0.406 0.416 0.330
4	281	1 2 3	RADI TRAN VERT	DYN-9319	Bldg 221 - 14 ft up Hush House side Center Column	254 77	89 27	269 82	161	187.02 211.86 169.72	2.02 1.94 2.47	0.438 0.451 0.325
5A	280	1		p-3	Apron Pressure	438 134	673 205	803 245	123	.145 mV/Pa	*	*
5B	280	2		p-2	Apron Pressure	438 134	469 143	642 196	133	.200 mV/Pa	*	*
5C	280	3		p-1	Apron Pressure	438 134	250 76	504 154	150	.113 mV/Pa	*	*
6	279	1		p-4	Bldg Site Pressure	530 162	953 290	1090 332	119	.157 mV/Pa	*	*
7	322	1 2 3	RADI TRAN VERT	DYN-9322	Bldg Site Seismics	530 162	953 290	1090 332	119	189.34 197.54 175.27	2.02 2.15 2.09	0.413 0.376 0.355
8	278	1 2 3	RADI TRAN VERT	DYN-9324	Highway Noise Seismics	874 266	1354 413	1612 491	123	171.55 136.63 181.35	1.94 2.04 2.34	0.401 0.354 0.336

4. DATA COLLECTION AND ANALYSIS

4.1 Hush House Operations

Field tests at the Fort Smith facilities were run from 22 to 24 October 1986. To support these tests, the Arkansas ANG arranged for three types of aircraft to be operated in the Fort Smith Hush House. These were an F-4, an F-15, and an F-16 fighter aircraft. In each case, the aircraft was positioned in the Hush House and the engines run through a sequence of power settings including idle, military power and afterburner. For military power and afterburner each setting was maintained for approximately 5 min while acoustic and vibration data were recorded. During some of the runs data were also collected for idle. At the conclusion of each run the equipment continued recording to establish background levels. In addition, separate noise samples were taken at each site.

In the case of the F-15, a twin engine aircraft, measurements were taken with one engine in idle and the other engine operating at the specified level. This was taken to be the worst case situation for the F-15. Only one of the two engines on the F-4 was used during the tests while the F-16 is a single engine aircraft.

Meteorological conditions during the test were essentially uniform. Typical conditions were full overcast or slight drizzle with wind speeds averaging 8 to 10 mph to the north or northeast and temperatures between 60 and 70° F. Although the conditions suggest the possibility of excess acoustic attenuation between the Hush House and the measurement sites, they did not appear to produce any unusual propagation conditions.

4.2 Standard Data Analysis

Reduction of the data collected during the field program followed a standard procedure. After conversion of the field tapes to computer compatible form, calibration data were processed to provide system responses. The raw data files were then reviewed for each site, aircraft, and power setting. A 100-sec data segment was typically selected for further processing. Data segments were selected to be free of recording problems, such as dropouts or extraneous signals, and to avoid non-stationary signals that occur during engine power changes. A visual review of the full raw data set was conducted to insure that the extracted sample was representative of the overall record from which it was taken.

Each data segment was processed to remove the appropriate system response function by frequency domain deconvolution. The output of this process was the true ground particle velocity or pressure. During deconvolution, a bandpass filter for the frequency range of 0.8 to 40 Hz was applied. It should be noted that this involved the boosting of signal power in the range above 30 Hz, the system

anti-aliasing filter corner frequency. It can be assumed that data in the frequency range above 30 Hz will have somewhat wider confidence bounds than data within the typical flat response band of 1 to 30 Hz. For subsequent analysis, the first and last 2.56 sec of data were ignored as the deconvolution process is unable to make full instrument response correction in these regions. Ground displacement was determined for the vibration data by time domain integration of the velocity traces, and where appropriate, acceleration was determined by time domain differentiation.

Each data trace was analyzed for statistical information and various data plots were generated. The nature of the Hush House infrasonic source is well represented as a stationary random process and raw time histories are typically unenlightening. The statistics obtained included mean, variance, root mean squared (rms) and the extreme value for each record, and the mean and variance of the peak absolute value within non-overlapping windows of 0.1, 0.25, 0.5 and 0.1 seconds.

Based on the windowed statistics, parameters of the Normal, Gumbel Extreme Value Type I and Type II distributions were calculated and tested against the observed distributions by means of the standard Kolmogorov-Smirnow test.^{8,9} In virtually all cases the highest level of acceptance was achieved for the 1-sec windows and only parameters for this window length are discussed.

Finally, power spectral density (PSD) plots were estimated for each channel. These spectra were obtained by averaging the periodograms for as many as 2.56 sec, non-overlapping windows as available in the data segments. Typically, this provided a highly stable spectrum with as many as 70 degrees of freedom (DOF). In addition to the spectrum, each plot also displays the maximum and minimum value found at each frequency. It should be noted that these extreme value data do not constitute the observed spectrum at any given point in time but are composites constructed from all of the observed spectra.

4.3 Comparison Motion Levels

The motion environment at any site provides little useful information without references against which to compare the observed levels. For this study five reference motion levels were used. The reference actually applied at any specific location would depend on the conditions and intended use of the site under consideration.

8. Benjamin, J.R., and Cornell, C.A. (1970) Probability Statistics, and Decision for Civil Engineers, McGraw-Hill Book Co., New York, NY.

9. Snedecor, G.W., and Cochran, W.G. (1980) Statistical Methods, The Iowa State University Press, Ames, Iowa.

4.3.1 BACKGROUND NOISE

Of some use is a comparison of the motion levels observed during Hush House operations and during ambient conditions. This comparison shows the direct effect of the Hush House operations on the undisturbed vibro-acoustic environment at each site. For this purpose ambient noise measurements were made at each location. With the exception of the highway noise survey at sites 7 and 8, the ambient environment was measured during normal working hours. For the highway noise survey, measurements were made at approximately 1630 local time when high levels of highway traffic induced noise could be anticipated. It should be noted that vibro-acoustic noise, particularly in a populated setting, is only short term stationary and is highly dependent on time of day, day of the week and time of year. Due to the limited duration of this study, these noise samples do not reflect a complete statistical characterizations of the ambient conditions at each site.

4.3.2 EQUIPMENT SPECIFICATIONS

The supplier of F-16 avionics test equipment has specified vibration criteria for this equipment.¹⁰ The manufacturer's specifications are based on the prevention of damage to non-operating equipment. Operating criteria are not stated. These criteria are applicable to vibration data collected at sites 1 and 2 in the Avionics Building. The peak to peak displacement criteria specified by the supplier are reproduced in Table 3. As provided, these criteria are not directly comparable to the measured data and can be interpreted in several ways for the purpose of comparison.

Before proceeding, it should be noted that the bandwidth of the observed data, 0.8 to 40 Hz, does not completely cover the window specified by the manufacturer, 5 to 55 Hz. Two factors show that this is not significant to the results of this report. First, as can be seen from the data collected during this and previous studies,^{4,5} Hush-House induced acoustics decay fairly rapidly above about 20 Hz. For linear systems, as the emitted energy decreases, the ability of the Hush House to drive structures at these frequencies is also reduced. Second, at higher frequencies the response of a structure becomes governed by local effects such as the resonance of individual wall panels. Local effects are virtually impossible to consider in a generalized context and are usually easy to resolve on a case by case basis.

10. General Dynamics Corp., F-16A/B, F-16C/D Facilities Requirements & Design Criteria, 16PRO38, Fort Worth Division, Fort Worth, TX.

Table 3. Motion Criteria for the F-16 Avionics Test Benches¹⁰

Frequency Band (Hz)	Peak to Peak Displacement		Effective PSD Level (meters ² /Hz)
	(inches)	(meters)	
5 to 15	0.06	0.0015	5.6×10^{-10}
15 to 25	0.04	0.0010	2.5×10^{-10}
25 to 55	0.02	0.0005	2.1×10^{-11}

NOTE: The effective PSD level is inferred from the manufacturer's specifications based on relations stated in the test.

The most stringent application of the criteria would be to take the lowest level, that for the frequency band of 25 to 55 Hz and use it as an absolute maximum level for the entire measured bandwidth of 0.8 to 40 Hz. As the maximum ground displacement observed over the full window (5 to 55 Hz) can not be any less than that generated within a subset of the frequencies, this interpretation assures that the full criteria is met. Thus, it is assumed that the manufacturer's specifications for the F-16 avionics test equipment are met when the observed absolute zero to peak displacement is less than 2.5×10^{-4} meters.

A second means of conversion would be to evaluate a limiting power spectral density (PSD) function based on the stated criteria. The PSD level for each frequency band specified can be approximated as:

$$L(f) = \text{rms}^2 / (f_1 - f_0) \quad (1)$$

where $L(f)$ is the PSD level such that, if all frequencies within the bandwidth f_0 to f_1 have equal amplitudes, the criteria will be exceeded, and rms is the root mean square amplitude of the causative disturbance. This relationship can be derived from Parseval's Theorem assuming that the all signal power is contained in the bandwidth f_0 to f_1 .

The problem, however, is to define the rms value, given that the equipment criteria specify only the peak to peak values and not a distribution of the values. If sinusoidal input is assumed, then the rms value can be obtained as $(0.707) (1/2) (PP)$ where PP is the peak to peak displacement of the criteria. However, based on the observed distributions of Hush House generated signal, the ratio of the displacement rms value to the maximum zero to peak value is in the

range of 0.1 to 0.3. To be conservative, the low ratio of 0.1 was used to define the rms value from the specified peak to peak values.

The effective PSD levels for each frequency window can be evaluated as:

$$L(f) = \frac{[(0.1) \left(\frac{1}{2}\right) (PP)]^2}{f_1 - f_0} \quad (2)$$

where all values are defined as before. Using this relation, effective PSD levels were evaluated for the F-16 avionics test benches and are also given in Table 3.

4.3.3 OPERATIONAL CRITERIA

As stated above, the manufacturer's criteria are intended to insure protection against damage but do not relate to any necessary conditions for satisfactory operation. Several potential guidelines do exist for operational conditions. First, the Air Force Metrology and Calibration Program has stated that accelerations of 10^{-2} to 10^{-5} m/sec² are tolerable for vibration sensitive operations.¹¹ The basis of this criterion could not be established. This value is, however, comparable to a second criterion, an rms value of 3×10^{-3} m/sec², proposed by the U.S. Environmental Protection Agency (EPA) for hospitals and critical working areas.¹² The EPA level is an operational criterion for motion sensitive facilities. The recommended measurement location for this criterion is on the floor. This would seem to imply that motion amplification between the floor and the working surfaces has been considered in establishing this criterion. The necessity of satisfying this criterion for successful operation of the F-16 avionics test benches is unknown. It is likely that this value constitutes a lower limit and motions above this level could be tolerated without adverse effect.

4.3.4 SAFETY OF STRUCTURES

The previously stated criteria can be applied to determine the appropriateness of a site for housing motion sensitive operations. However, for Building 221 the question is the safety of the structure. The EPA has also proposed guidelines for this purpose.¹² The structural damage guidelines are summarized in Table 4. The stated levels in Table 4 are for the vector sum of the peak velocities on three orthogonal axes. In general, these guidelines were developed from data based on vibrations generated by quarry blasting. They are also held to be applicable for steady or intermittent vibrations such as those anticipated from Hush House operations.

11. Personal Communication, Alan Witten, Oak Ridge National Laboratory, 1987.

12. U.S. Environmental Protection Agency (1982) Guidelines for Noise Impact Analysis, EPA Report No. 550/9-82-105, Washington, D.C.

Table 4. Guidelines for Estimating the Potential of Structural Damage¹²

Velocity (m/sec)	Damage Level
< 0.0025	Damage Not Possible
0.0025 to 0.0060	Damage Very Improbable (Onset of visible cracks in non-structural members.)
0.0060 to 0.0100	Damage Not Probable (Stresses should be checked. Onset of visible cracks in structural members with no serious load carrying capacity.)
> 0.0100	Damage Possible (Stress check necessary)
0.0300 to 0.1000	Available Data Insufficient to Define Type of Damage
> 0.1000	Onset of Permanent Damage (Possible load bearing reduction.)

NOTE: Velocity is vector sum of maximum peak velocities on three orthogonal axes.

It is significant that these criteria are based on a bandwidth of 1 to 100 MHz while the measurements were made with a bandwidth of 1 to 40 Hz. As the inclusion of higher frequencies can only increase the amplitude of a signal, the measured levels given in this report must be considered lower limits when compared to this criterion. If the criterion is approached in the band limited data, then it is highly likely that the criterion will be exceeded in the full 100 Hz bandwidth.

For most practical purposes a vector sum peak velocity of 0.025 m/sec is defined as the threshold of damage and can be interpreted as the lowest velocity level at which structural integrity could become a potential issue.¹² As Building 221 is basically a pre-engineered hangar type structure with little interior structure, it is concluded that this level is most appropriate for evaluating the impact of Hush House operations on this structure.

5. HUSH HOUSE INDUCED MOTIONS

5.1 Overview

The following section provides details of the observed environments at each measurement point and, where appropriate, makes comparison with the appropriate criteria from those cited above. This section is organized into subsections dealing with the observed Hush House acoustic emissions and the motion levels in the Avionics Building, Building 221 and at the proposed construction site for a new Avionics facility. Additional statistical information derived from the observed data is also presented in Appendix B of this report.

5.2 Hush House Acoustic Emissions

Pressure emissions from the Fort Smith Hush House were monitored at three points located just north of the aircraft parking area in the ANG facility and at the potential site of a new avionics facility (Figure 2). The locations of these sensors, sites 5A, 5B, 5C, and 6 were at distances of 154, 196, 245, and 332 meters respectively, from the exhaust deflector of the Hush House. These sites were selected to provide estimates of the pressure loads on Building 221, site 5A, at the Avionics Building, site 5C, at an open, unobstructed location, site 5B and the possible construction site, site 6. All transducers were positioned at ground level and recorded surface pressures. Surface pressures, over a rigid earth, are twice the level that would be recorded in the free field away from any boundaries.

5.2.1. TIME DOMAIN ANALYSIS

Figure 5 shows the pressure time histories recorded at sites 5A, 5B and 5C for an F-16 in the Hush House and running in afterburner. As with almost all of the data collected during this study, plots of the time histories provide very little insight into the problem. The acoustic signatures exhibit the characteristics of a stationary random processes. From direct examination of the records for both military power and afterburner and for all three aircraft, the only easily discernible difference between the time traces is the strength of the signal. As should be expected, tracking of major excursions in the records indicates a speed of sound in air of approximately 350 m/sec.

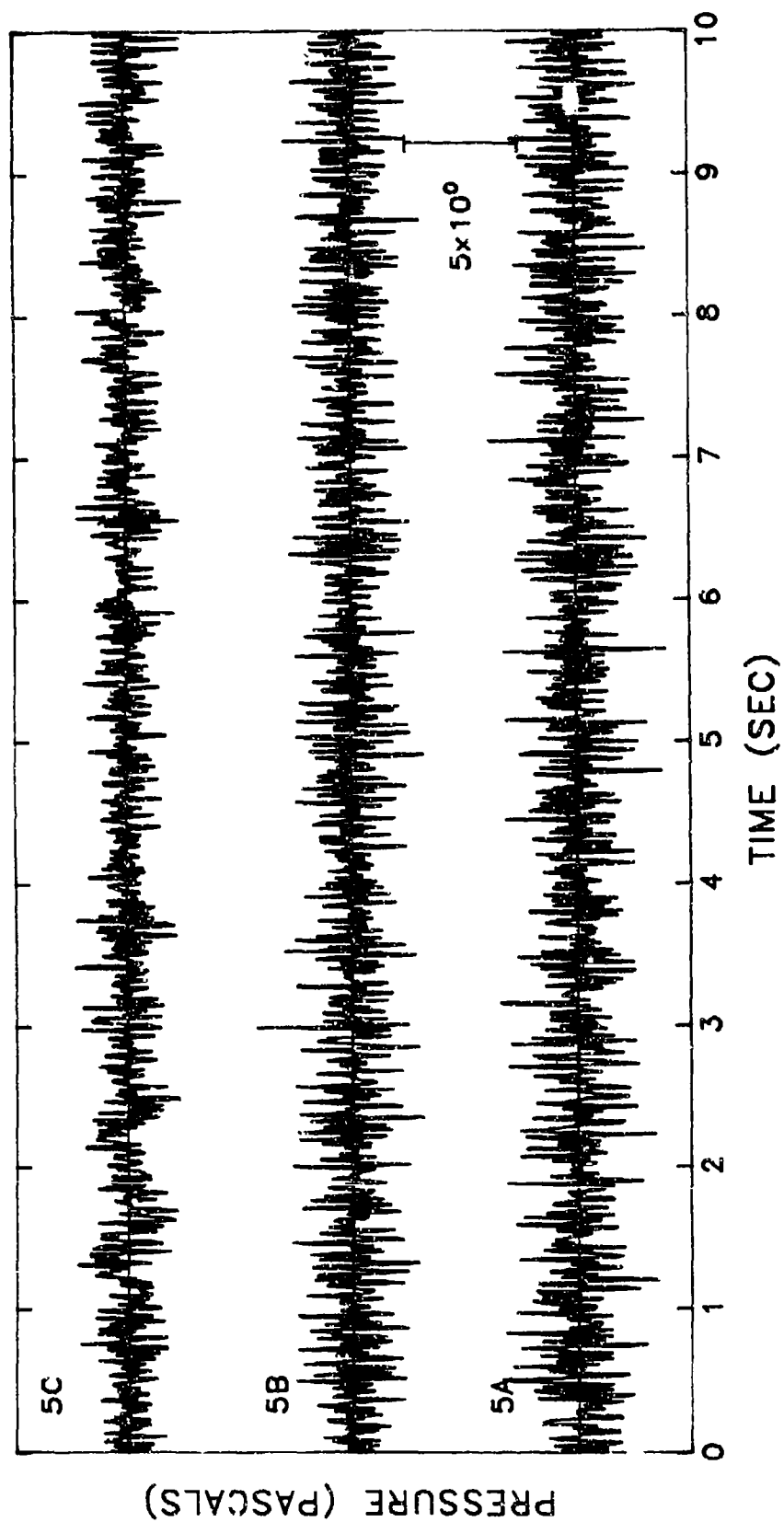


Figure 5. Observed Pressure Time Histories for an F-16 in Afterburner in the Hush House at Sites 5A, 5B, and 5C

Statistical analysis of the pressure histories provides a simple means to compare the apparent Hush House acoustic source strengths for the various aircraft and engine power level combinations. A summary of the statistics for the pressure measurements is given in Table 5 and a full listing of the evaluated statistics for each data sample appears in Appendix A. Without consideration of frequency content of the signals, it is apparent that the Hush House source strengths for the F-16 and F-15 are virtually identical in terms of acoustic emission levels and, the F-4 has a source strength of about 0.6 times that of the F-16 or F-15 at similar power. These ratios appear to hold without regard to the engine power setting. As a corollary, the normalized source strength as a function of power setting appears to be independent of the engine type. Relative to the rms level for afterburner, the source strength for military power is about 0.4. For idle, the source strength was found to be 0.2.

The pressure levels evaluated for idle have low confidence as the observed levels are not much greater than ambient wind levels and are close to the lower limit of sensitivity of the pressure measurement system. Insufficient low end range was a particularly acute problem at site 6. All runs at this site in idle and military power for the F-4 produced insufficient signal strength to warrant processing.

Beaupre and Crowley have demonstrated that the Hush House infrasonic emissions can largely be treated as being generated in a small source region 10 meters over the exhaust deflector.⁵ Along lines of constant azimuth and at distances over 50 meters from the source, the emissions satisfy far-field spherical acoustics. It was also noted, however, that the source has an azimuthal and frequency dependent radiation pattern. Although the sites used in the Fort Smith study do not lie along any one azimuth but are spread over an arc of about 30 degrees, an attempt was made to use the observed rms values to verify far-field spherical propagation. This analysis assumes that the azimuth dependency of the radiation pattern is compensated by the fact that the rms value averages over the entire measurement bandwidth. An equation of the form:

$$\ln[p(r)] = a - c * \ln[r] \quad (3)$$

was fit to the available values for each aircraft type and power level. In this equation r is the radial distance from the exhaust deflector to the observation point, $p(r)$ is the rms pressure level at that site, and a and c are the regression constants. The value of c , the attenuation coefficient, is the power of r governing the rate of attenuation of pressure amplitude. For true far-field spherical propagation the value of c is one.

Table 5. Statistics of the Observed Acoustic Emissions
From the Fort Smith ANG Hush House

Aircraft	Power Level	Site	rms Level (Pascals)	Maximum Observed Level (Pascals)
F-4	IDLE	5A	0.123	0.481
		5B	0.042	0.187
		5C	0.048	0.356
	MIL	5A	0.326	1.302
		5B	0.287	1.159
		5C	0.175	0.705
	AB	5A	0.763	2.953
		5B	0.714	3.028
		5C	0.423	1.628
		6	0.381	1.627
F-15[1]	IDLE	5A	0.249	1.762
		5B	0.087	0.462
		5C	0.071	0.570
	MIL	5A	0.485	1.877
		5B	0.436	1.625
		5C	0.321	1.379
		6	0.263	1.041
	AB	5A	1.339	4.960
		5B	1.205	4.681
		5C	0.931	3.472
		6	0.574	3.228
F-16	IDLE		NOT RECORDED	
	MIL	5A	0.492	2.154
		5B	0.451	1.882
		5C	0.325	1.519
		6	0.285	0.756
	AB	5A	1.339	4.953
		5B	1.140	4.963
		5C	0.845	4.287
		6	0.468	1.296

[1] One engine in power level and one engine in idle.

A mean attenuation coefficient of 1.0 was found for all engines in afterburner or military power; in agreement with far-field spherical propagation. The range of values for different days was 0.8 to 1.3 but the attenuation coefficient was consistent for each engine type. The variation in c can be explained as a function of the azimuthal dependency of the radiation pattern, meteorological conditions, the smoothing effect of using an rms value, or some combination of the three. In any case, given the small number of sites used for the fitting, the agreement with far-field spherical acoustics is considered good.

Significantly, the attenuation coefficients for idle were found to be 2.7 for the F-15 and 2.1 for the F-4. These values are vastly different from the coefficients found for higher power settings and are well above the theoretical range for far-field acoustic propagation.

It is assumed that this radical change in the apparent attenuation indicated that, at best, only a weak jet source is established during idle and the data are dominated by ambient conditions. The pressure levels for idle are, in essence, the ambient conditions at each location. In this case theory would imply that the attenuation coefficient should drop to zero. That it did not appears to be attributable to the fact that site 5A, the closest site to the Hush House, was the most unprotected from the prevailing winds and had much higher wind noise than the other sites. The high wind noise at this site biased the regression and produced an apparent attenuation of the total pressure "signal" with distance.

5.2.2 FREQUENCY DOMAIN ANALYSIS

The lack of a strong jet acoustic source during idle can readily be seen by comparing the pressure PSD plots for idle against those for other power settings (Figures 6 through 13). In the band 3.0 to 40 Hz, all spectra for military power and afterburner show the general characteristics observed in Hush House emissions; a bell-shaped spectrum peaking in the range of 15 to 20 Hz with a secondary maximum located below 10 Hz (see Appendix A).^{4,5} The spectra for idle do not demonstrate this structure and are not atypical of the structure of wind noise.¹³ As a well developed source was not identified for aircraft operating at idle, only data for military power and afterburner will be considered for the remainder of this report.

13. Beranek, L. L. (1971) Noise and Vibration Control, Mc-Graw Hill Book Company, New York, N.Y.

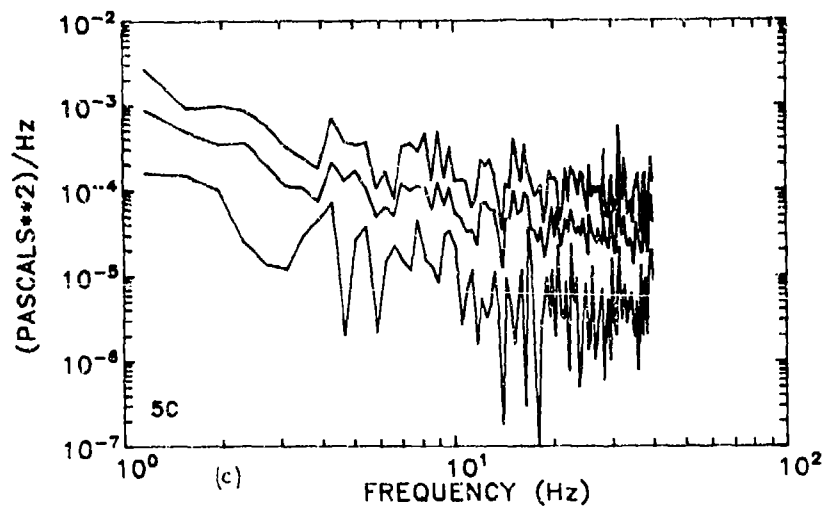
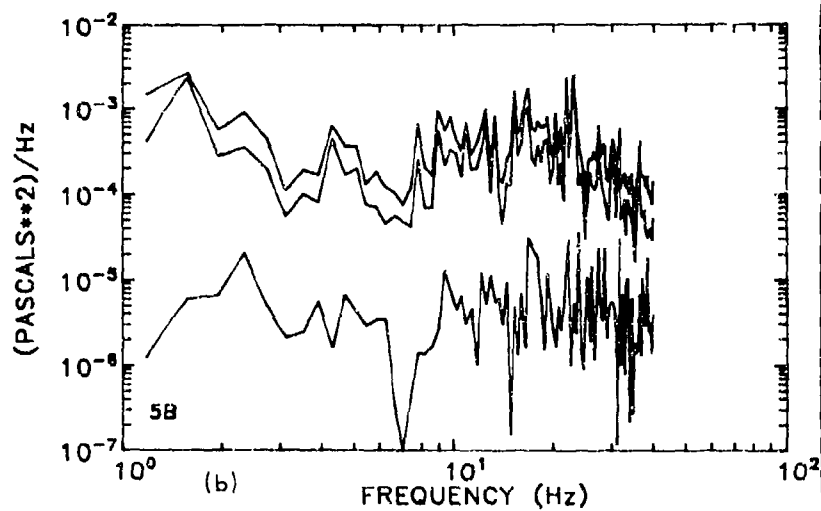
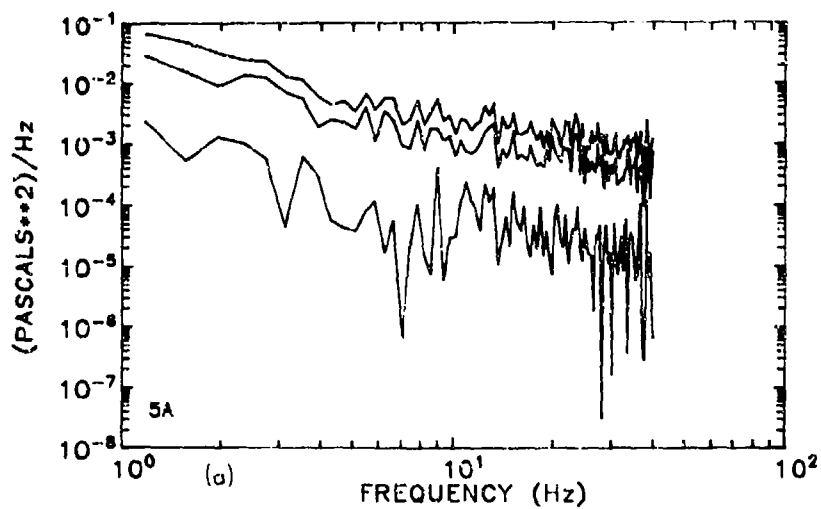


Figure 6. Pressure PSD for an F-4 at idle in the Fort Smith Hush House at Sites (a) 5A, (b) 5B, and (c) 5C. The middle curve is the mean spectrum while the upper and lower curves represent the extreme values at each frequency

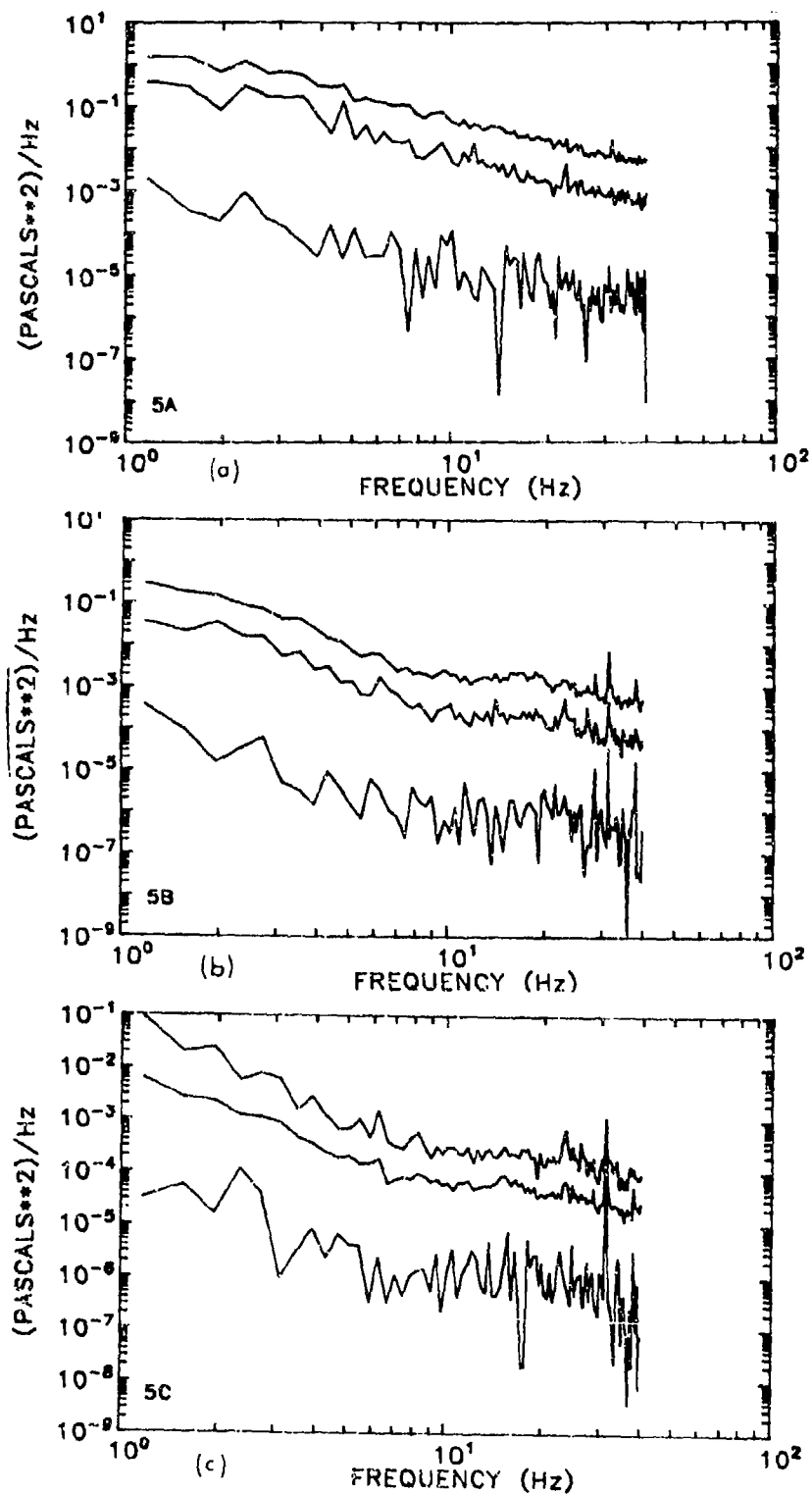


Figure 7. Pressure PSD for an F-15 at Idle in the Fort Smith Hush House at Sites (a) 5A, (b) 5B, and (c) 5C. The middle curve is the mean spectrum while the upper and lower curves represent the extreme values at each frequency

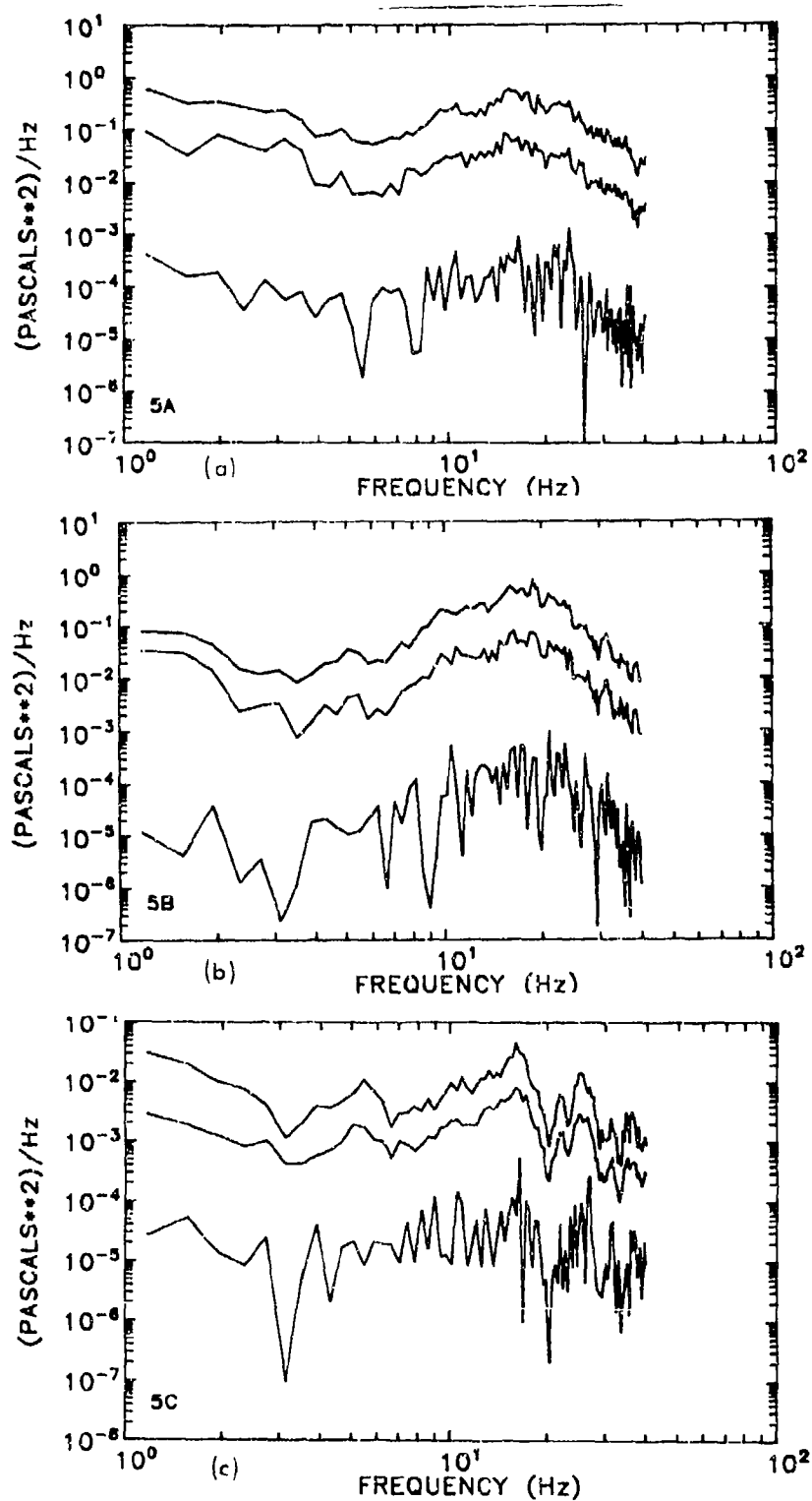


Figure 8. Pressure PSD for an F-4 at Military Power in the Fort Smith Hush House at Sites (a) 5A, (b) 5B, and (c) 5C. The middle curve is the mean spectrum while the upper and lower curves represent the extreme values at each frequency

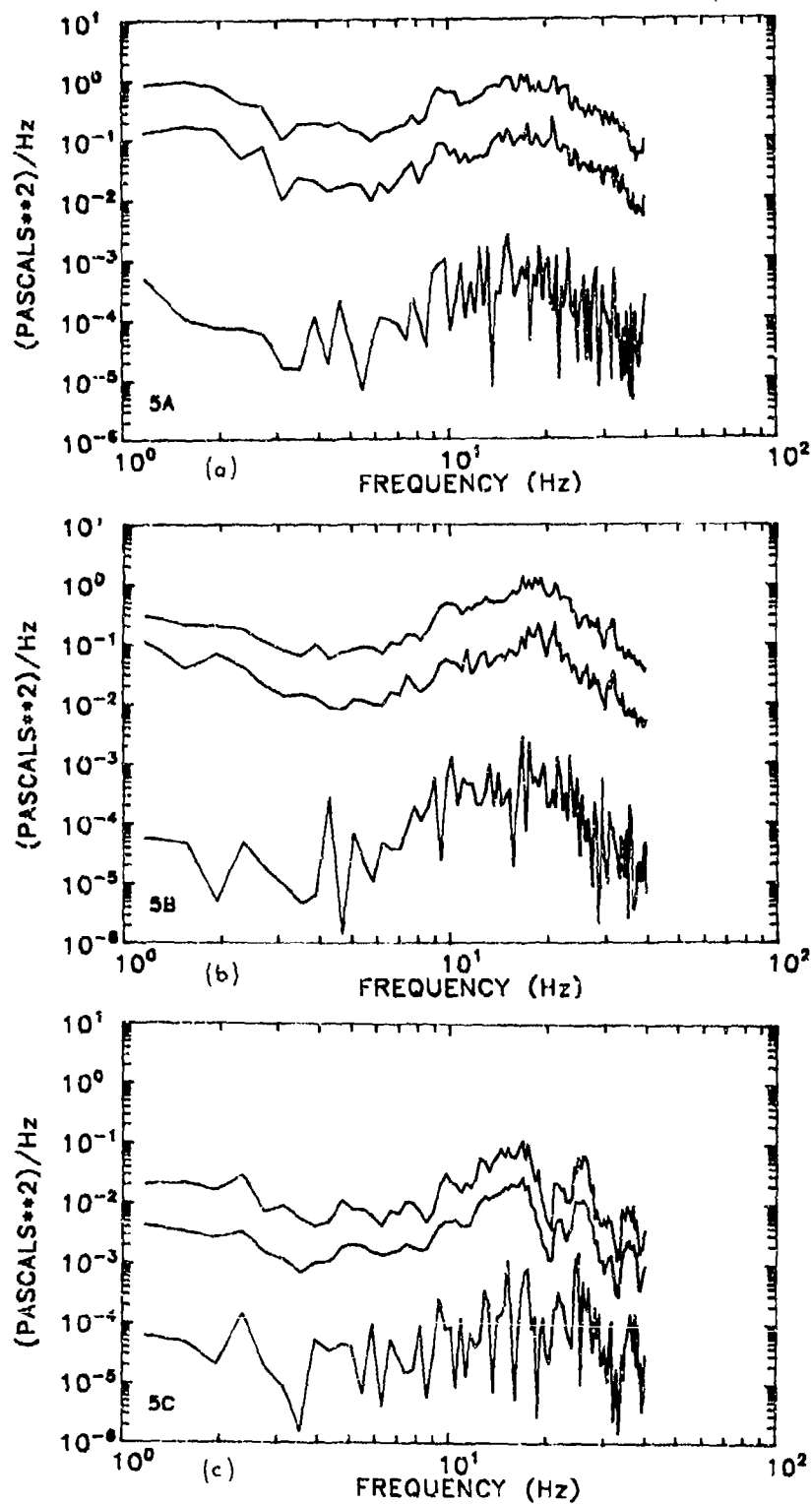


Figure 9. Pressure PSD for an F-15 at Military Power in the Fort Smith Hush House at Sites (a) 5A, (b) 5B, and (c) 5C. The middle curve is the mean spectrum while the upper and lower curves represent the extreme values at each frequency

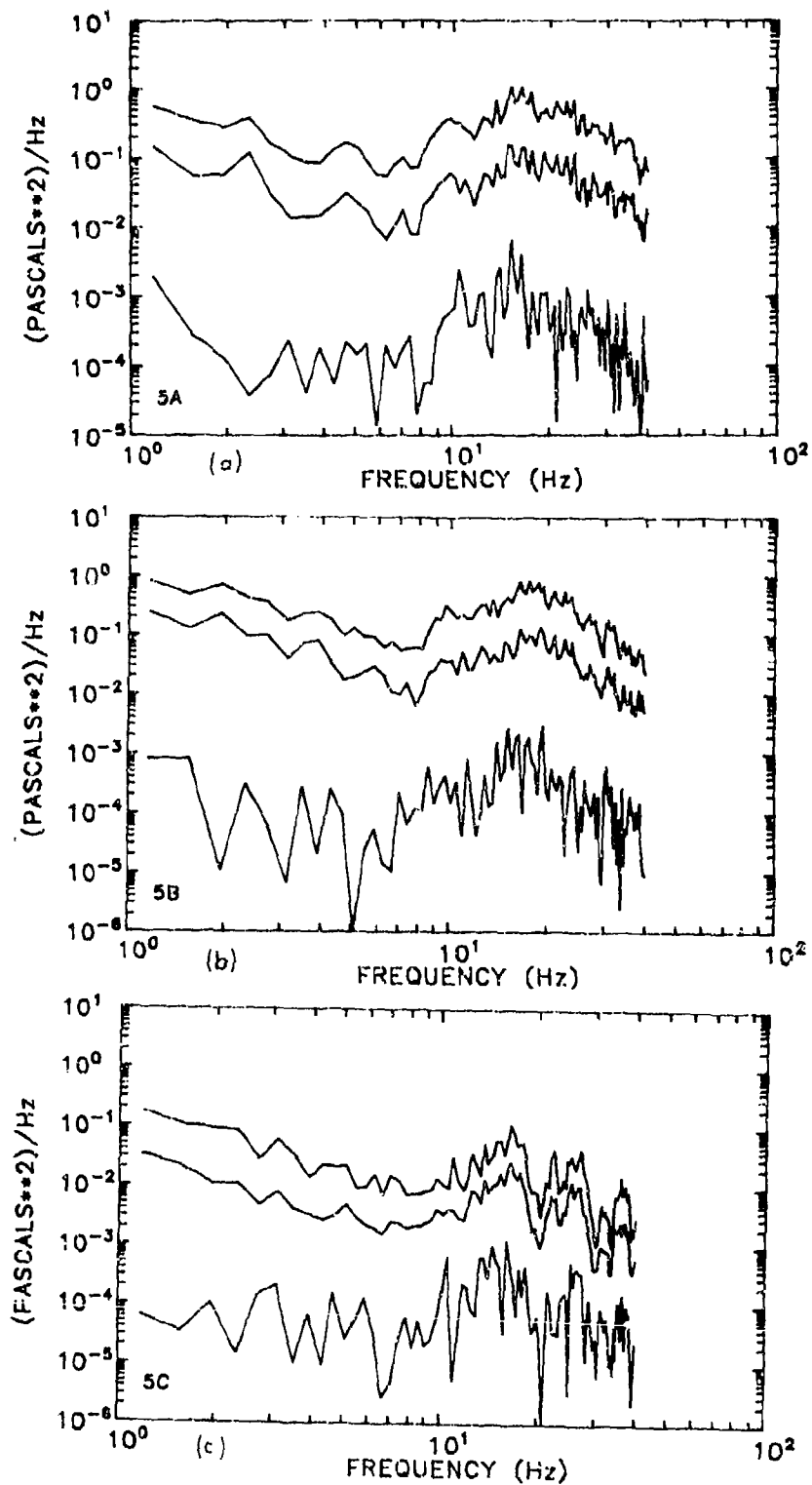


Figure 10. Pressure PSD for an F-16 at Military Power in the Fort Smith Hush House at Sites (a) 5A, (b) 5B, and (c) 5C. The middle curve is the mean spectrum while the upper and lower curves represent the extreme values at each frequency

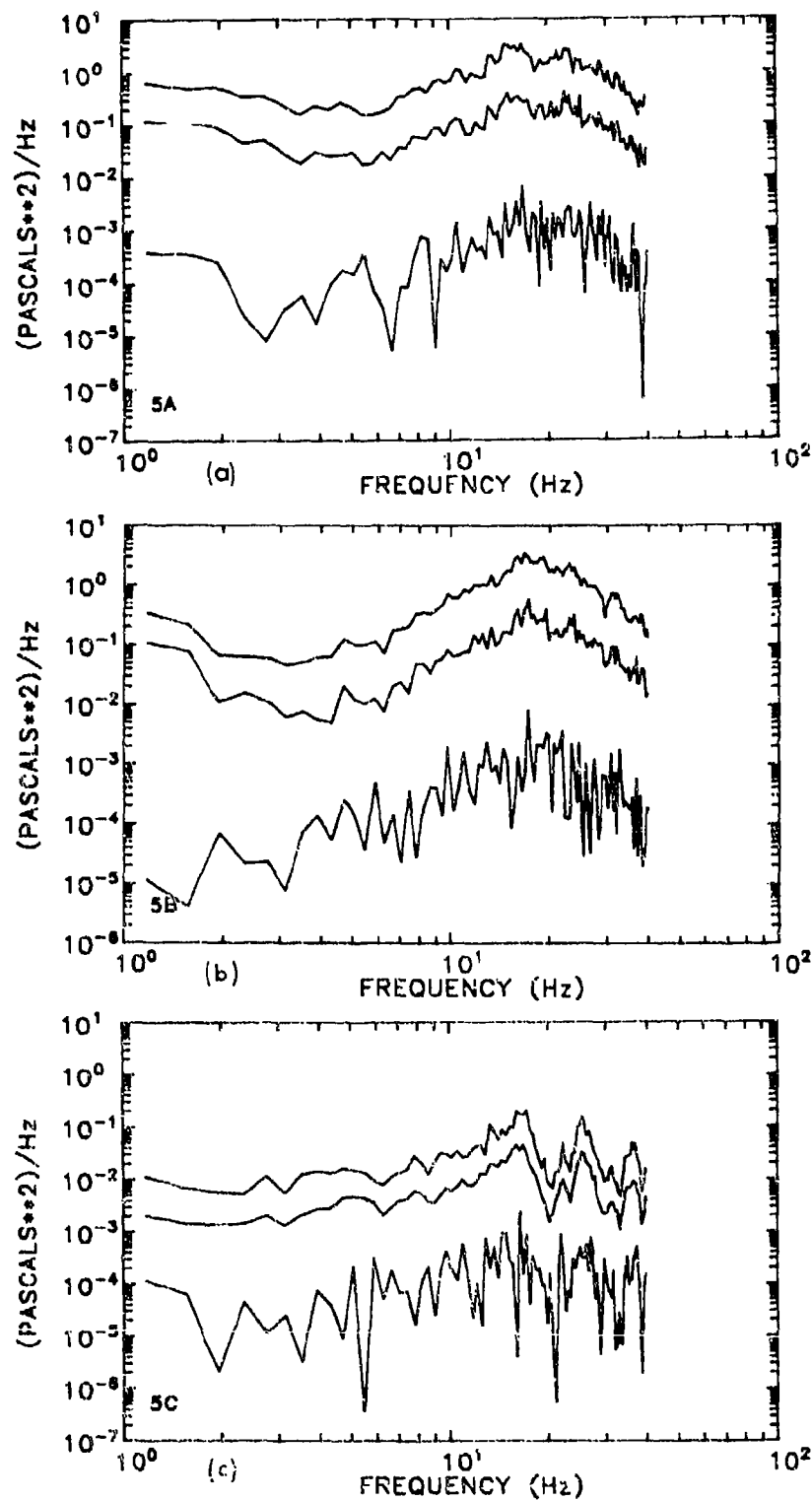


Figure 11. Pressure PSD for an F-4 in Afterburner in the Fort Smith Hush House at Sites (a) 5A, (b) 5B, and (c) 5C. The middle curve is the mean spectrum while the upper and lower curves represent the extreme values at each frequency

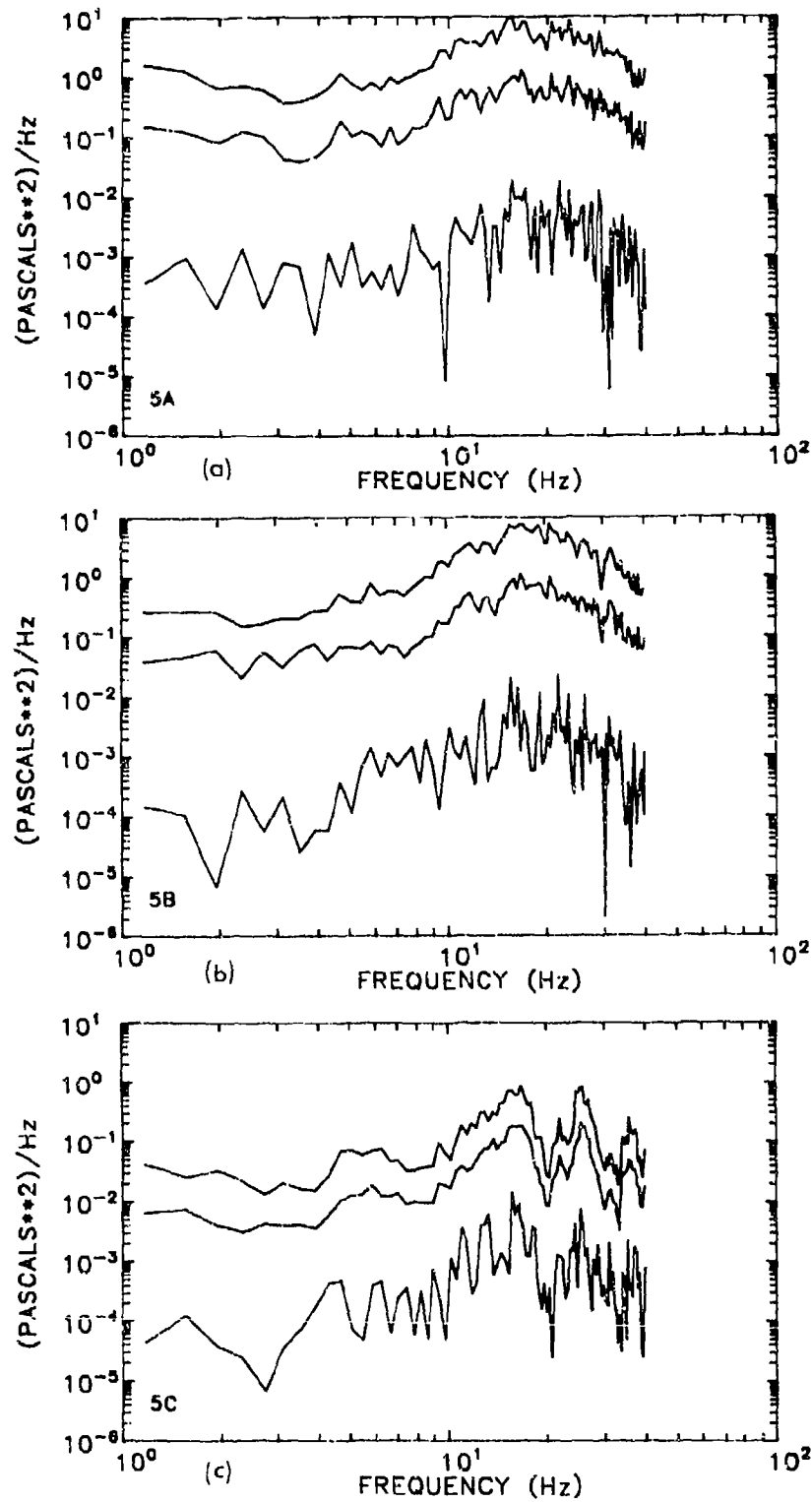


Figure 12. Pressure PSD for an F-15 in Afterburner in the Fort Smith Hush House at Sites (a) 5A, (b) 5B, and (c) 5C. The middle curve is the mean spectrum while the upper and lower curves represent the extreme values at each frequency

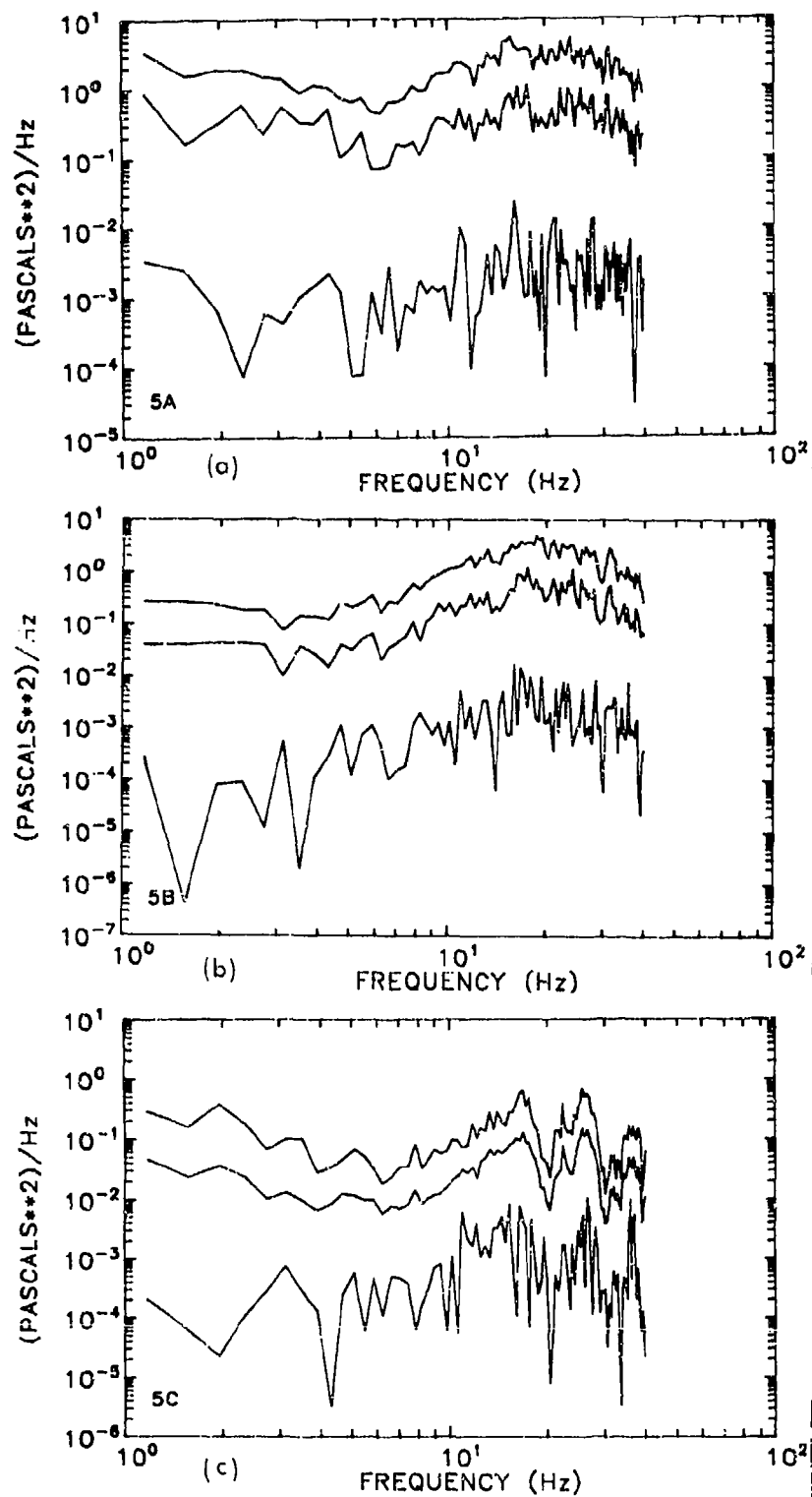


Figure 13. Pressure PSD for an F-16 in Afterburner in the Fort Smith Hush House at Sites (a) 5A, (b) 5B, and (c) 5C. The middle curve is the mean spectrum while the upper and lower curves represent the extreme values at each frequency

With the exception of the F-4 idle spectra shown in Figure 6, spectra have at least 50 degrees of freedom (DOF) and, more typically, 70 DOF. Due to the short data segments used for the F-4 in idle, the spectra in Figure 6 have only 14 degrees of freedom which accounts for its more ragged appearance as compared to other PSD plots.

As discussed in Appendix A, the characteristic frequency of the primary jet noise source is sensitive to the velocity of the air passing through the fixed diameter exhaust tube. This frequency should increase as the airflow through the engine increases. The anticipated frequency shift can be detected in these spectra as the higher relative PSD levels above 20 Hz for all aircraft in afterburner as compared to the same aircraft in military power.

This behavior is better seen in the smoothed spectral ratio presented in Figure 14. The ratio curves were obtained by evaluating, at each site, the ratios of spectra for each run against that of the F-15 in afterburner and then averaging across the sites. For runs in military power, the negative slopes of the spectral ratios show the low relative amplitudes at high frequencies corresponding to lower center frequencies for the main source spectral component. The positive trend of the F-16 in afterburner suggests a higher center frequency than the F-15 in the same mode. The peaks below 10 Hz show the change in frequency of the secondary lobe with power setting.

Most of the spectral ratios in Figure 14 are fairly smooth and well behaved. This suggests that a fairly simple Hush House acoustic emissions model could be developed that could be scaled directly from the parameters of the engine of interest. For the F-16 in afterburner, however, there is more pronounced spectral structure at the higher frequencies. This structure appears to be real as it is consistent in the ratios at each site. The cause, however, is not obvious and may warrant further study.

Peak observed pressures for the F-15 and F-16 in military power and afterburner are found to be comparable with levels observed at the Luke AFB Hush House for the F-100 engine outside of the aircraft.⁵ It has been suggested that the Hush House source could be sensitive to whether the engine is in or out of the aircraft. If this is true then the effect appears to be of small consequence and unlikely to have a significant effect on siting criteria. Also, the second engine running at idle during the F-15 operations appears to have negligible effect on the infrasonic emissions. The emission characteristics are defined by the engine at highest thrust.

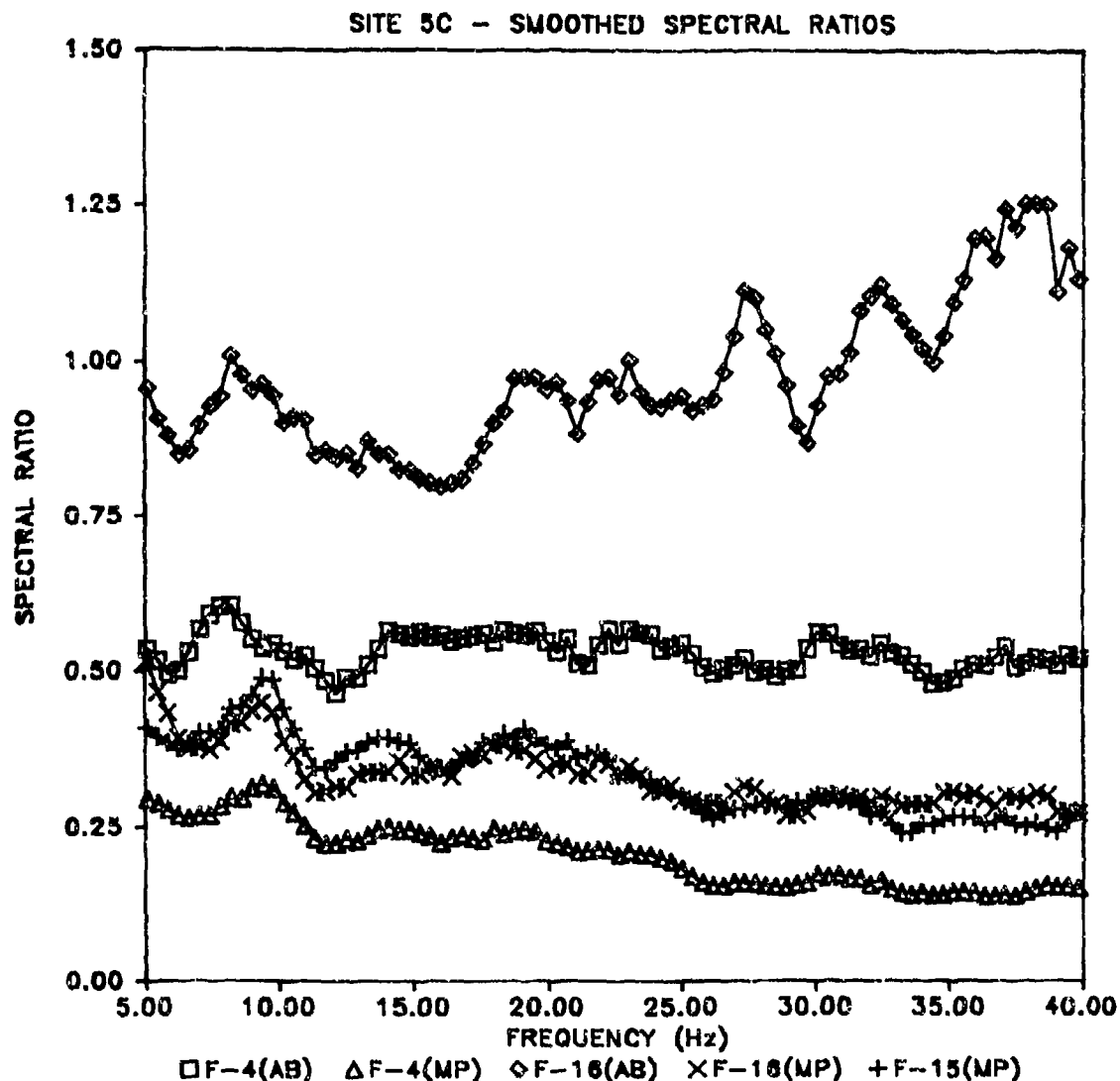


Figure 14. Smoothed Spectral Ratios Relative to the F-15 in Afterburner for the F-4 and F-16 in Military Power and Afterburner and the F-15 in Military Power

Of particular interest in the spectra for site 5C are the obvious notches between about 17 and 23 Hz and 28 and 45 Hz. These holes are observed in all military power and afterburner runs but are not observed in spectra for either noise or idle runs. (This fact demonstrates that they are not related to instrument response.) Spectral nulls are typically found for data exhibiting multipathing, or multiple arrivals from the same source with some fixed time delay. Considering the positions of possible reflectors near the site it is most likely that the nulls result from an echo off the Avionics Building itself. In this case, the pressure loading function on the Avionics facility should not contain these spectral nulls and can be better

represented by the spectral shape found at site 5B. Later in this report, the analysis of the structural responses at the Avionics Building will show this to be true.

5.3 Avionics Building Motions

Velocity transducers were located on the floor slab of the Avionics Building at two locations; in the warehouse section, site 1, and near the base of the Inertia Measurement Unit (IMU) pedestal in the workshop area, site 2. During the F-15 runs the transducer at site 2 was placed on the IMU pedestal to investigate the impact of Hush House operations at the top of the pedestal, a potentially sensitive work surface. The sensors were oriented such that one horizontal component was directed towards the Hush House exhaust deflector and the other perpendicular to this direction. The components are labeled as the radial and transverse components, respectively and this convention was observed at all other sites as well.

5.3.1 TIME DOMAIN ANALYSIS

Figure 15 shows a typical 10-sec displacement trace for data recorded at site 1 with an F-16 in afterburner in the Hush House. It is of interest to note the change in dominant frequency between these traces and the pressure time histories shown in Figure 5. From this change it should be apparent that the response characteristics of any specific building play a major role in defining the motion environment that can be induced by Hush House operations.

In general, however, time histories are not a useful form for presentation of Hush House induced motions as the data is well represented by a stationary random process. The data are better represented in the form of their statistical parameters. Table 6 summarizes the statistics on observed displacements and accelerations in the Avionics Building. More complete statistics can be found in Appendix B of this report. While Normal, Extreme Value Type I and Type II distributions were fit to the observed data, it was found that the Extreme Value Type I distribution best fit the observed distributions of 1.0-sec windowed peaks and it is the parameters of this distribution that are used in the statistical presentations.

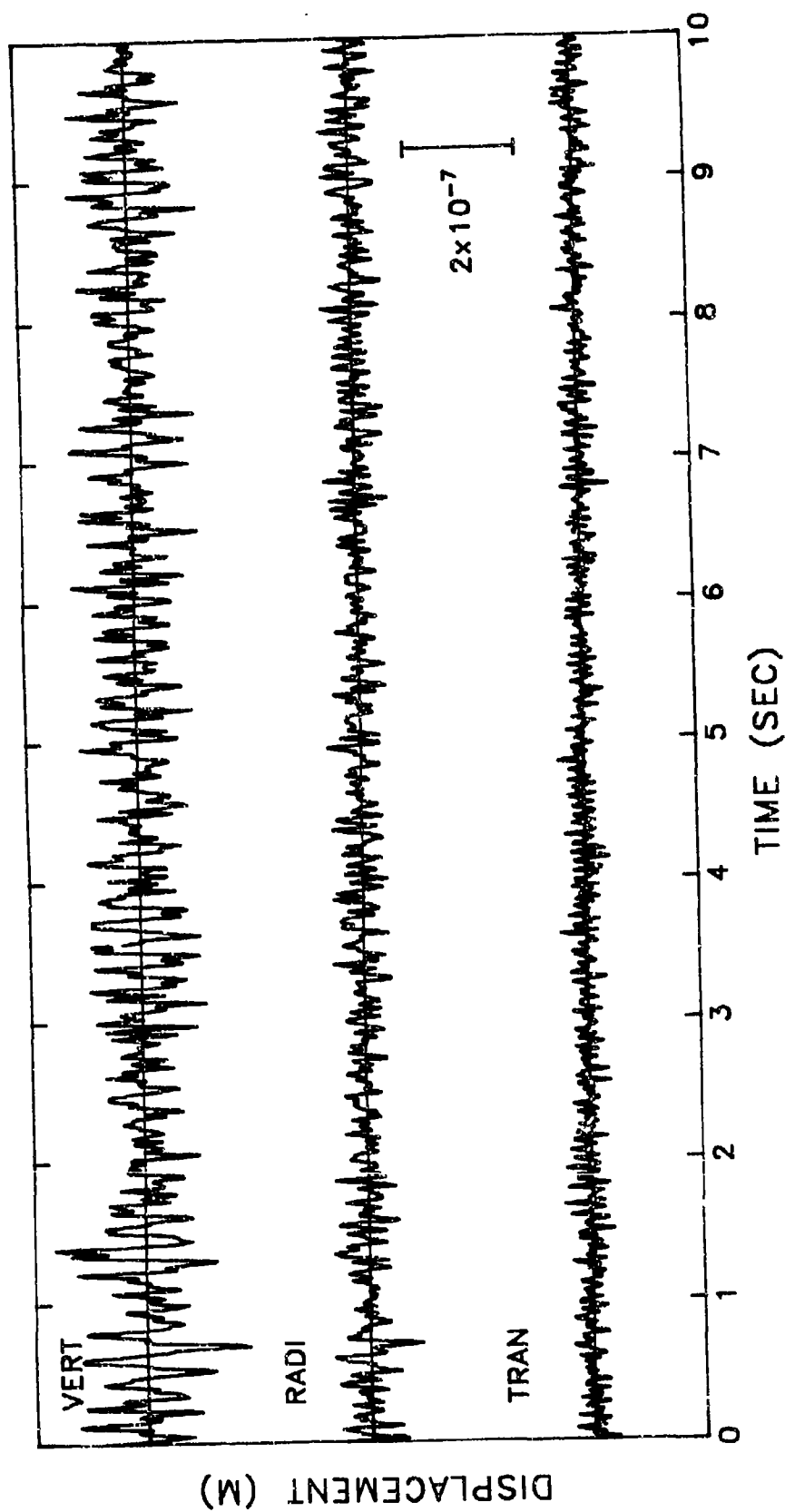


Figure 15. Observed Displacement Time History at Site 1 in the Avionics Building for an F-16 in Afterburner in the Hush House

Table 6a. Statistics of the Observed Motion Environment in the Fort Smith Avionics Facility

(Site 1)

Aircraft	Power Level	Comp	Full Distribution	1 Second Window Distributions			rms Accel. (in 10 ⁻³ m/sec ²)
			rms Level (all in 10 ⁻⁷ meters)	Normal 0.001% Exceed-ence Level	Normal 0.001% Exceed-ence Level	Extreme Type I 0.001% Exceed-ence Level	
F-4	MIL	R	0.103	0.334	0.476	0.594	0.065
		T	0.102	0.316	0.583	0.790	0.055
		V	0.184	0.568	0.891	1.156	0.092
	AB	R	0.188	0.570	0.755	0.913	0.141
		T	0.141	0.434	0.570	0.702	0.134
		V	0.323	0.999	1.256	1.526	0.225
F-15	MIL	R	0.153	0.472	0.615	0.750	0.087
		T	0.139	0.428	0.661	0.873	0.076
		V	0.231	0.714	1.000	1.260	0.125
	AB	R	0.341	1.053	1.328	1.605	0.219
		T	0.226	0.697	0.964	1.195	0.202
		V	0.630	1.946	2.589	3.273	0.351
F-16	MIL	R	0.117	0.361	0.457	0.547	0.080
		T	0.077	0.237	0.329	0.401	0.071
		V	0.194	0.600	0.806	0.991	0.119
		R	0.236	0.728	0.978	1.191	0.187
		T	0.155	0.478	0.608	0.721	0.181
		V	0.469	1.450	1.889	2.336	0.304

Table 6b. Statistics of the Observed Motion Environment in the Fort Smith Avionics Facility

(Site 2)

Aircraft	Power Level	Comp	Full Distribution		1 Second Window Distributions		
			rms Level	Normal 0.001% Exceed-ence Level	Normal 0.001% Exceed-ence Level	Extreme Type I 0.001% Exceed-ence Level	rms Accel. (in 10^{-3} m/sec ²)
				(all in 10^{-7} meters)			
F-4	MIL	R	0.039	0.119	0.157	0.191	0.024
		T	0.040	0.125	0.168	0.205	0.036
		V	0.033	0.101	0.144	0.187	0.012
	AB	R	0.057	0.177	0.234	0.282	0.051
		T	0.075	0.230	0.300	0.363	0.075
		V	0.040	0.125	0.182	0.231	0.027
	MIL	R	0.140	0.432	0.647	0.827	0.205
		T	0.178	0.548	0.837	1.069	0.312
		V	0.084	0.259	0.328	0.430	0.020
F-15	AB	R	0.305	0.943	1.239	1.515	0.599
		T	0.561	1.734	2.189	2.700	1.036
		V	0.088	0.271	0.344	0.436	0.044
	MIL	R	0.042	0.131	0.184	0.228	0.033
		T	0.047	0.144	0.193	0.233	0.046
		V	0.030	0.092	0.152	0.199	0.019
	AB	R	0.069	0.212	0.279	0.333	0.082
		T	0.088	0.271	0.362	0.439	0.095
		V	0.046	0.141	0.184	0.224	0.039
F-16	MIL	R	0.042	0.131	0.184	0.228	0.033
		T	0.047	0.144	0.193	0.233	0.046
		V	0.030	0.092	0.152	0.199	0.019
	AB	R	0.069	0.212	0.279	0.333	0.082
		T	0.088	0.271	0.362	0.439	0.095
		V	0.046	0.141	0.184	0.224	0.039
	MIL	R	0.042	0.131	0.184	0.228	0.033
		T	0.047	0.144	0.193	0.233	0.046
		V	0.030	0.092	0.152	0.199	0.019
	AB	R	0.069	0.212	0.279	0.333	0.082
		T	0.088	0.271	0.362	0.439	0.095
		V	0.046	0.141	0.184	0.224	0.039

NOTE: F-15 runs with transducer on IMU pedestal. All other runs with transducer on floor slab at pedestal base.

It is apparent that the observed displacement environments at these sites are well below the manufacturer's criteria for the avionics test benches, as interpreted in Section 4.3.2 of this report, 2.5×10^{-4} meters. Taking the worst case, the F-15 in afterburner, and using the Extreme Value Type I 0.001 percent exceedance level, the criterion is more than 650 times greater than this very conservative peak displacement estimate for the site.

Several noise samples were analyzed to provide an estimate of the "typical" background level in the Avionics Building. The rms noise displacements found for site 1 were about 0.5 to 1.0×10^{-8} meters on each component and 0.2 to 0.9×10^{-9} meters at site 2. Contrasting these values with the displacements given in Tables 6a and 6b, the F-4, for both military power and afterburner, generates motions only slightly above the ambient at these locations. The motions generated by the F-15 and the F-16 in afterburner exceed ambient conditions by less than an order of magnitude. However, the variation about these rms levels is much less for ambient conditions than for the Hush House excited motions.

In terms of the EPA critical working area criterion, the floor level rms acceleration are, in the worst case, an order of magnitude below the specified accelerations. In the workshop area, a site presumably similar to the potential locations of the F-16 avionics test benches, the floor level rms accelerations are significantly lower than those found at site 1. On the basis of this criterion, the Avionics Building should be able to house motion sensitive functions.

Further, the motions found in this building for F-4 runs in afterburner exceeded the levels seen for the F-15 or F-16 in military power. If the F-16 support functions to be performed in this building are similar to those presently conducted in support of the F-4, and as no interference with the F-4 support activities has been reported, it can be concluded that no interference should be seen during F-16 runs for military power. Then any adverse impact of F-16 Hush House operations could only occur during afterburner runs. As these runs constitute a small percentage of Hush House operating time, the worst case adverse impact on the Avionics Building should be limited in occurrence and duration.

The motion levels observed at the base of the IMU pedestal are significantly lower than those in the warehouse section of the facility. In addition, vertical motions are most pronounced at site 1 while they are the smallest component at site 2. These effects can be explained by two facts. First, the warehouse section would be expected to have a higher response due to the high bay structure and a larger exposed area to pressure loading than the workshop section. Second, the sensors in the warehouse area were located at a point where the floor slab could be expected to flex more than it would near the IMU pedestal base due to load bearing structural elements near the IMU pedestal.

It is also noted that horizontal motions on top of the IMU pedestal are much greater than those at the base of the pedestal. This can be seen by comparing the site 2 data for the F-15 and F-16. The relative source strengths for these aircrafts are the same but the F-15 data was collected on top of the IMU pedestal and the F-16 data at the base. Even with this amplification due to the pedestal response, the rms acceleration levels are still below the EPA criterion for critical working areas.

5.3.2 SPECTRAL ANALYSIS

Figure 16 and 17 show typical noise displacement PSD plots for sites 1 and 2. It is instructive to start with the noise PSD plots as they demonstrate certain response characteristics of the avionics facility needed to understand Hush House excited vibrations. The structure of ambient noise spectra can be attributed to the spectral structure of the noise sources and the response characteristics of the building. For example, the peak at 20 Hz for site 1 can be attributed to a sub-harmonic of 60 Hz associated with the electronic equipment used in this facility.

Several peaks can be observed in these figures, particularly at frequencies around 3 to 8 Hz and, to a lesser degree, around 15 Hz. These peaks can be associated with the response characteristics of the building. The relative strengths of the peaks are influenced not only by the ease of excitation but also by the fact that noise field, the driving mechanism, tends to decrease with increasing frequency. Of significance, is the fact that these two frequency bands are nearly coincident with the two spectral maxima of Hush House infrasonics. The Avionics Building is particularly sensitive to Hush House emissions.

Figures 16 through 29 show the displacement PSD plots found for sites 1 and 2 during Hush House operations. In each of these plots, the influence of the two lobes of the Hush House acoustic source can be seen by high responses around 5 to 8 Hz and between 10 and 20 Hz. In terms of power spectral density, the worst case is site 1 with the F-15 in afterburner. The PSD levels in each spectral window at this location are below the manufacturer's criteria by at least a factor of 10^{-4} .

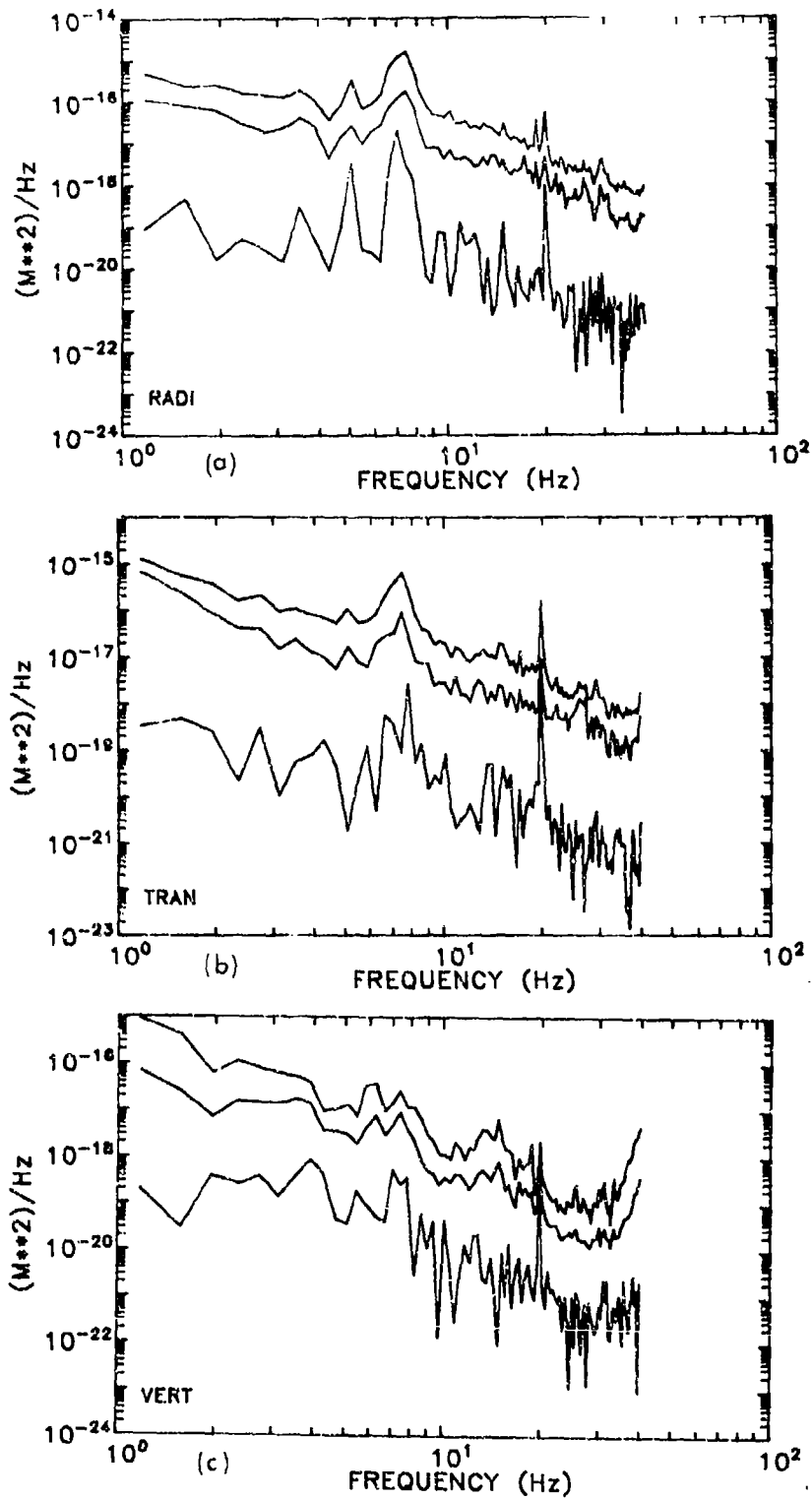


Figure 16. (a) Radial, (b) Transverse, and (c) Vertical Displacement Power Spectral Density Plots for Site 1 for Ambient Noise Conditions. In each plot the middle curve is the mean spectrum while the upper and lower curves represent the extreme values at each frequency

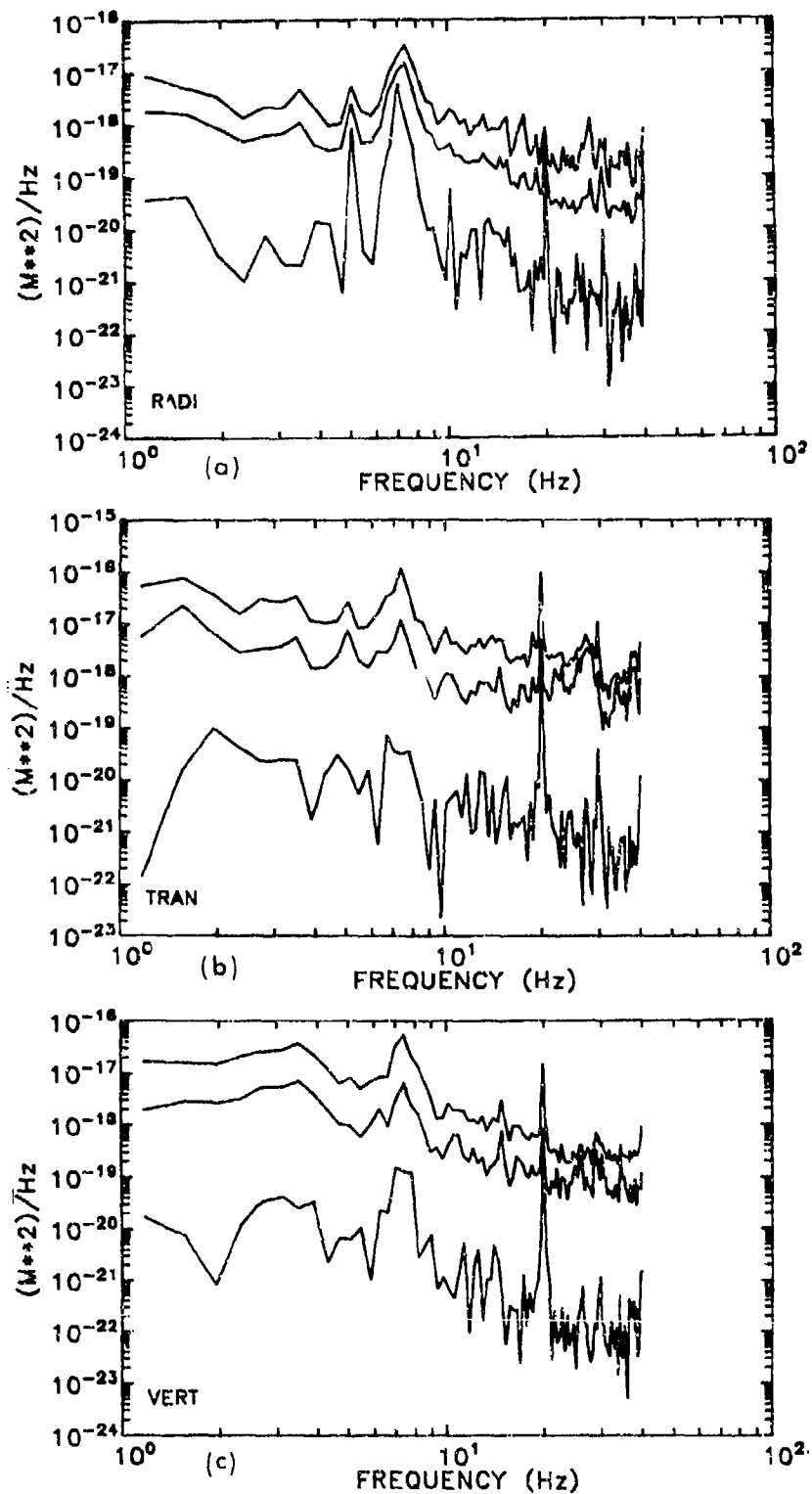


Figure 17. (a) Radial, (b) Transverse, and (c) Vertical Displacement Power Spectral Density Plots for Site 2 for Ambient Noise Conditions. In each plot the middle curve is the mean spectrum while the upper and lower curves represent the extreme values at each frequency

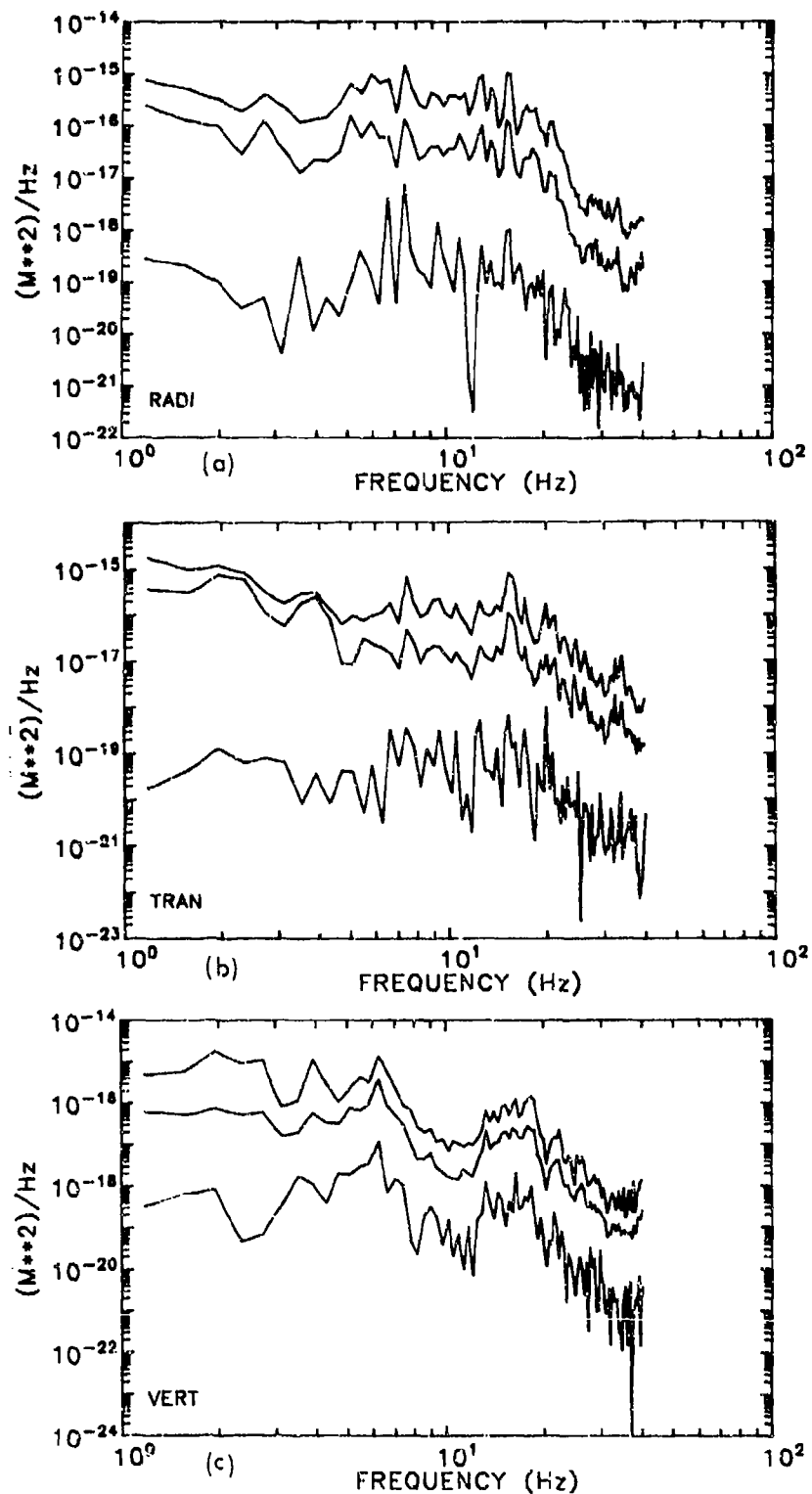


Figure 18. (a) Radial, (b) Transverse, and (c) Vertical Displacement Power Spectral Density Plots for Site 1 With an F-4 in Military Power in the Hush House. In each plot the middle curve is the mean spectrum while the upper and lower curves represent the extreme values at each frequency

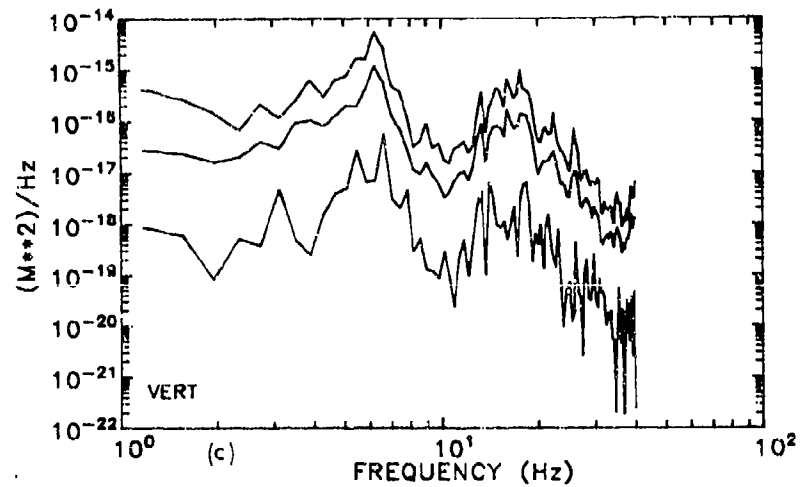
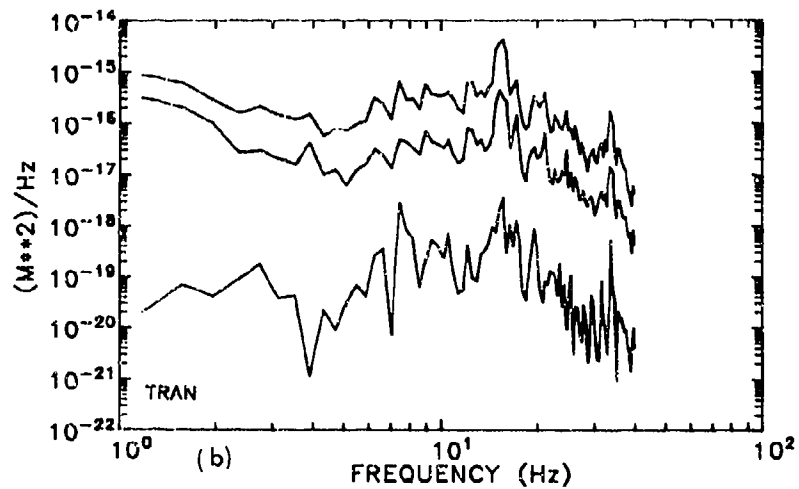
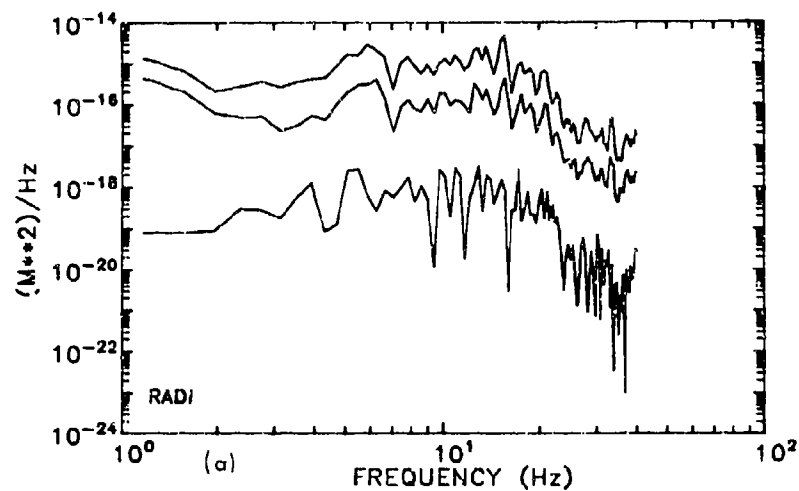


Figure 19. (a) Radial, (b) Transverse, and (c) Vertical Displacement Power Spectral Density Plots for Site 1 With an F-4 in Afterburner in the Hush House. In each plot the middle curve is the mean spectrum while the upper and lower curves represent the extreme values at each frequency

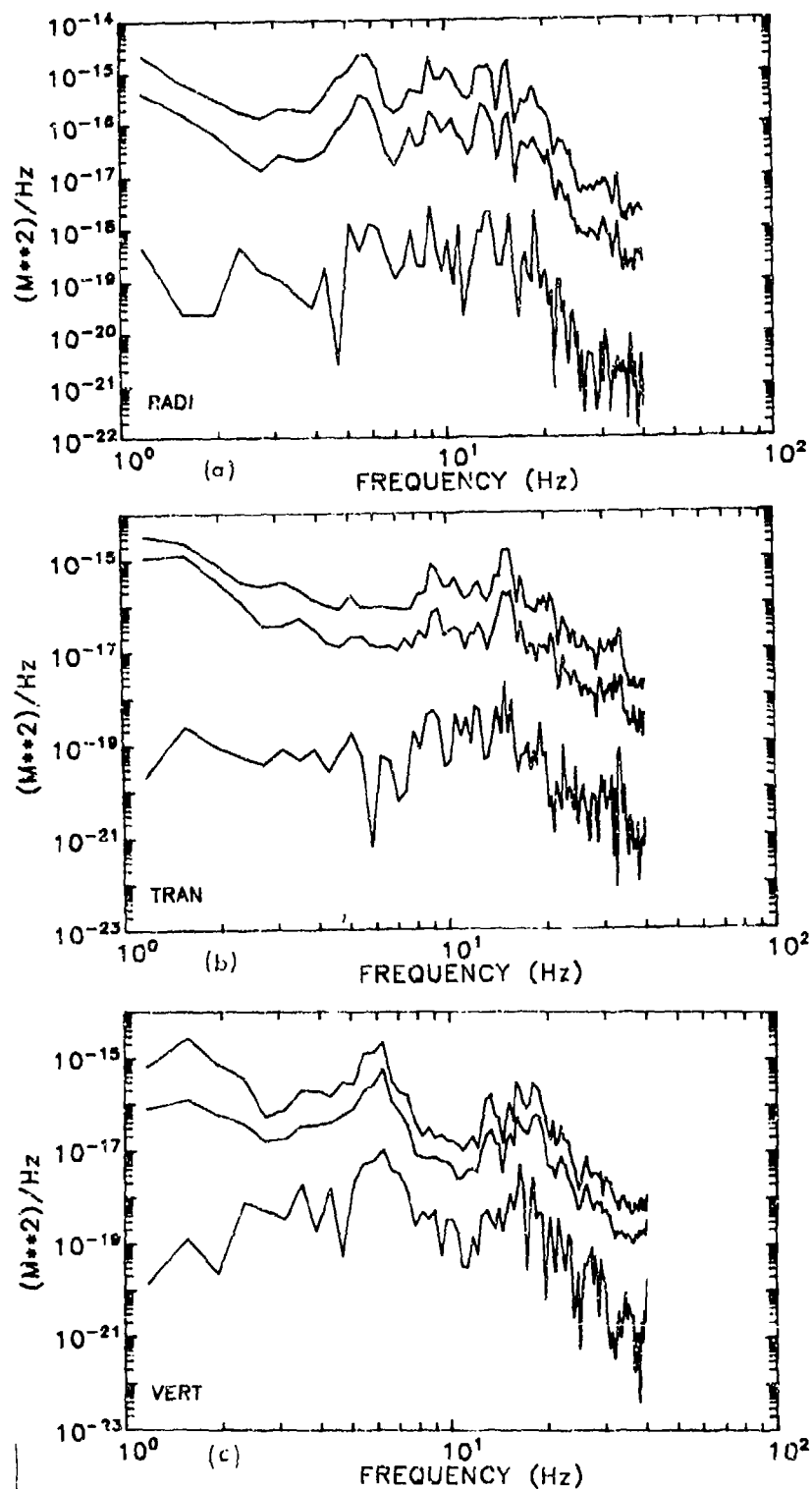


Figure 20. (a) Radial, (b) Transverse, and (c) Vertical Displacement Power Spectral Density Plots for Site 1 With an F-15 in Military Power in the Hush House. In each plot the middle curve is the mean spectrum while the upper and lower curves represent the extreme values at each frequency

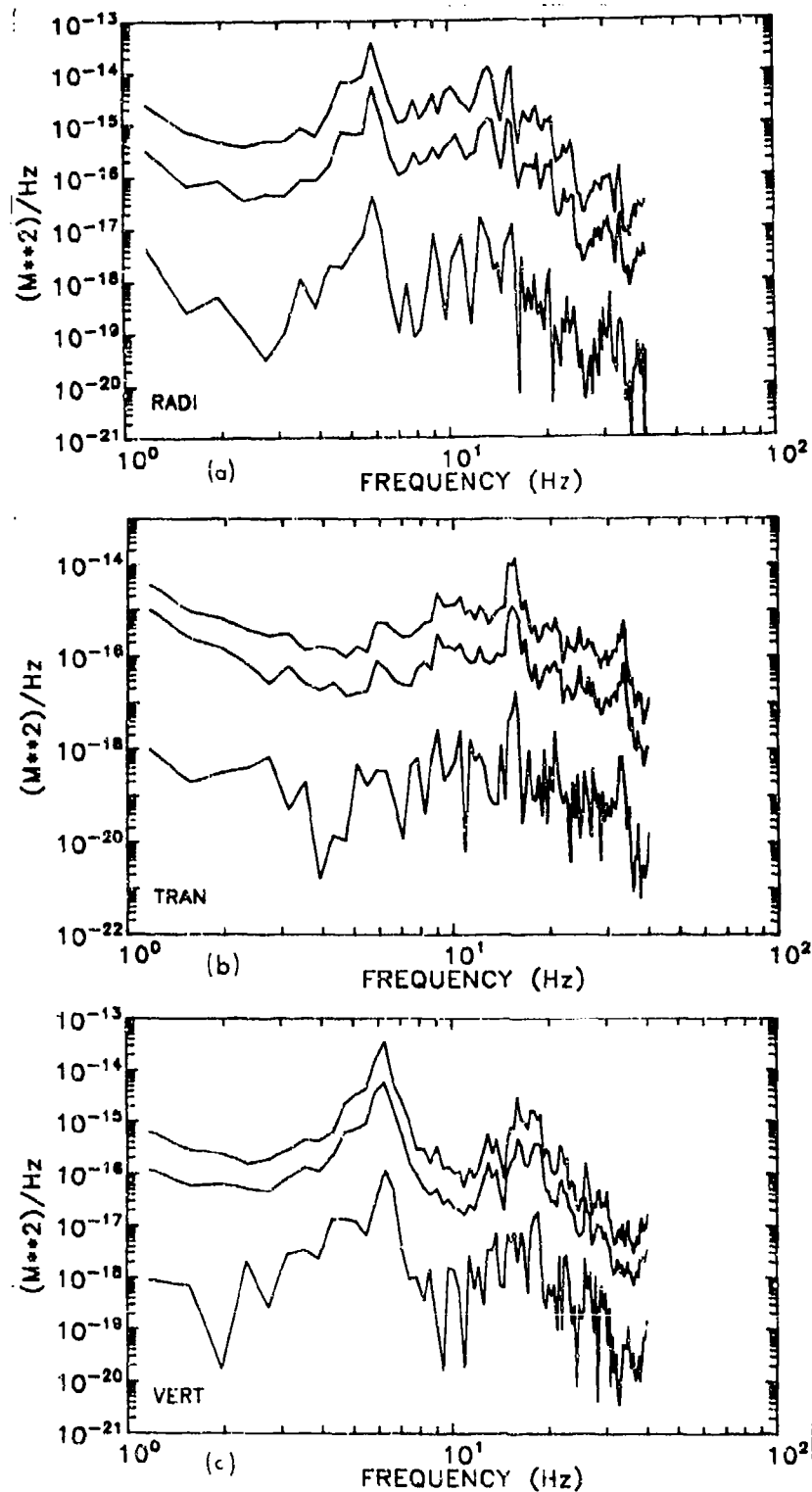


Figure 21. (a) Radial, (b) Transverse, and (c) Vertical Displacement Power Spectral Density Plots for Site 1 With an F-15 in Afterburner in the Hush House. In each plot the middle curve is the mean spectrum while the upper and lower curves represent the extreme values at each frequency

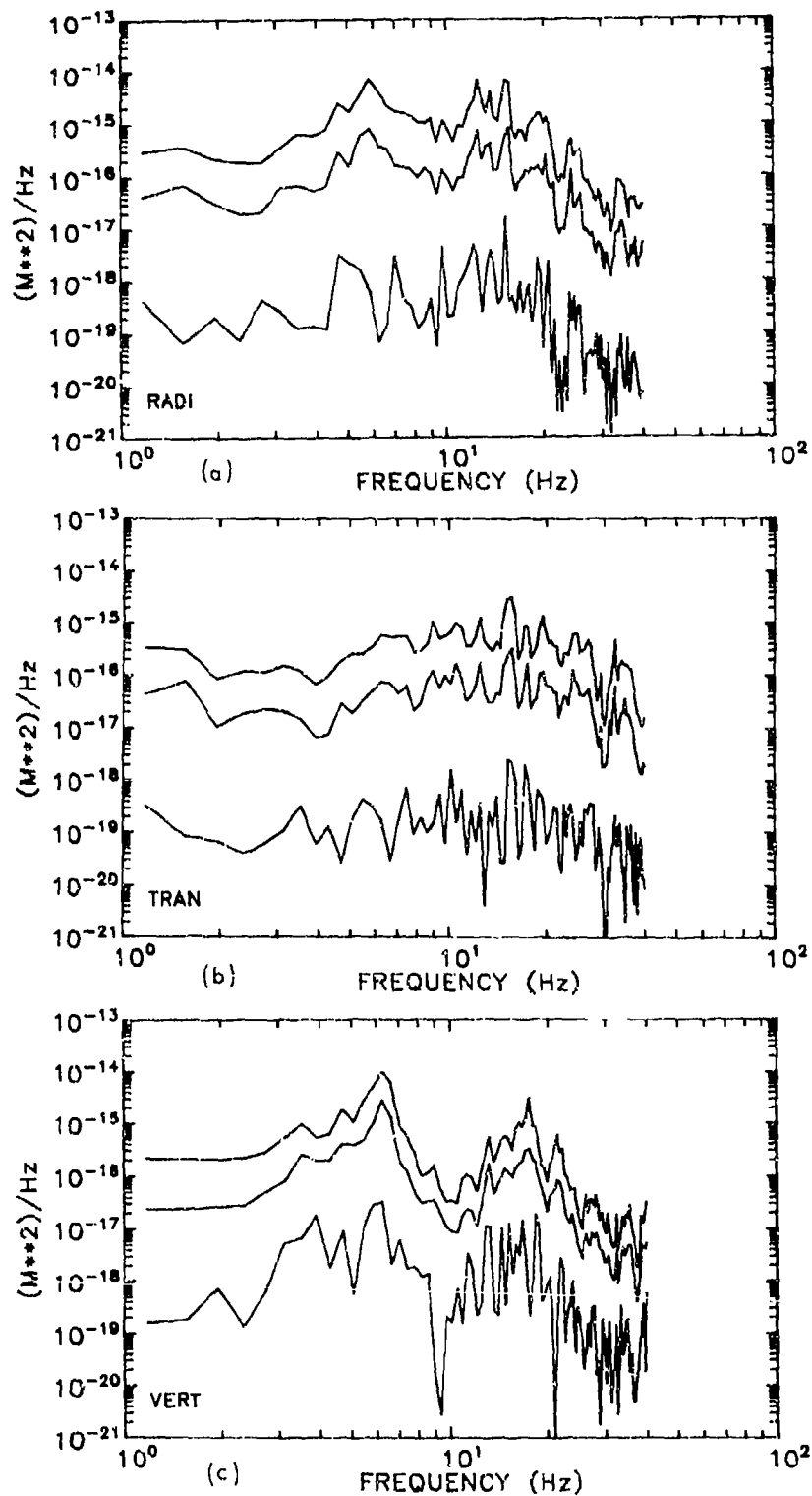


Figure 22. (a) Radial, (b) Transverse, and (c) Vertical Displacement Power Spectral Density Plots for Site 1 With an F-16 in Military Power in the Hush House. In each plot the middle curve is the mean spectrum while the upper and lower curves represent the extreme values at each frequency

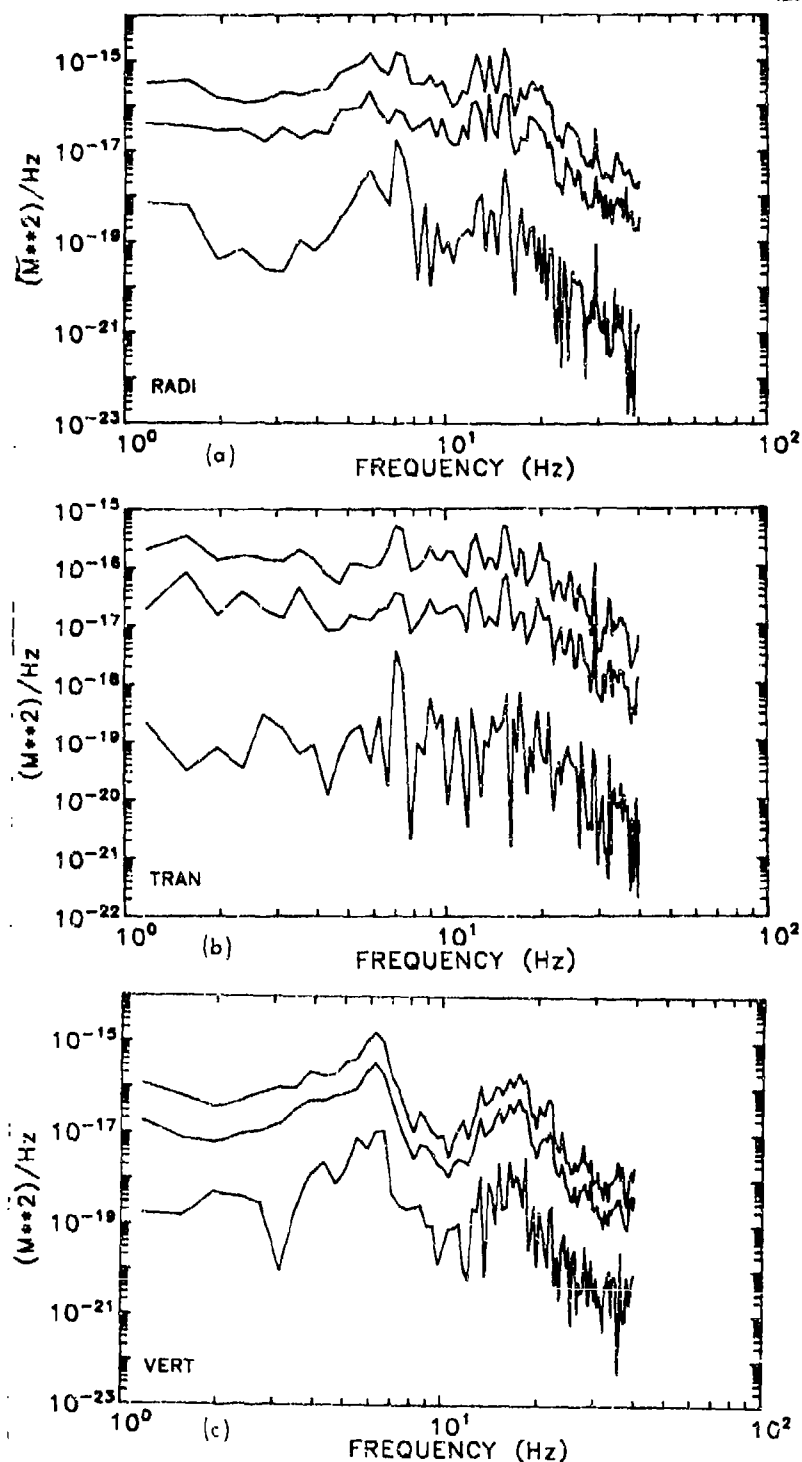


Figure 23. (a) Radial, (b) Transverse, and (c) Vertical Displacement Power Spectral Density Plots for Site 1 With an F-16 in Afterburner in the Hush House. In each plot the middle curve is the mean spectrum while the upper and lower curves represent the extreme values at each frequency

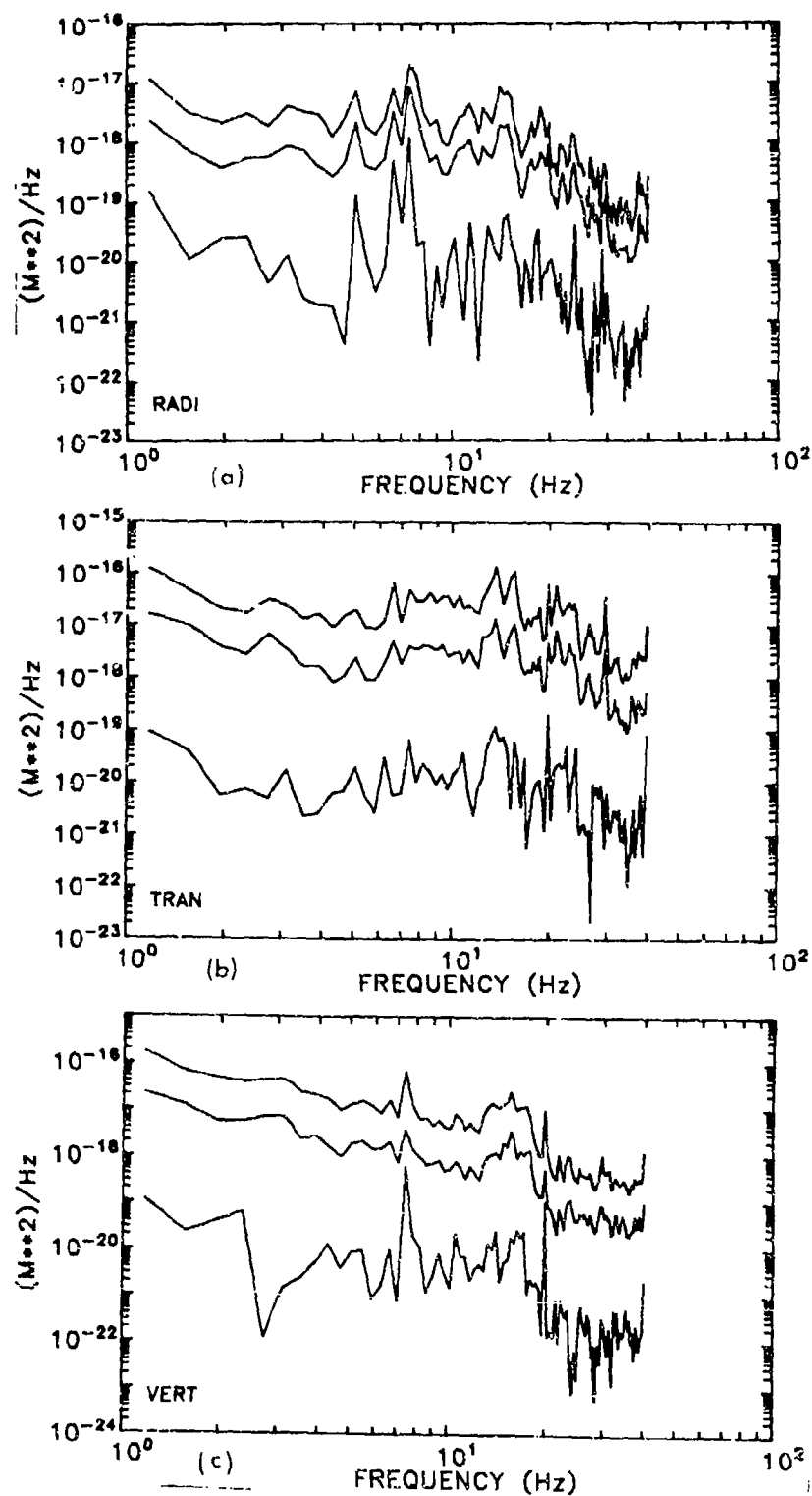


Figure 24. (a) Radial, (b) Transverse, and (c) Vertical Displacement Power Spectral Density Plots for Site 2 With an F-4 in Military Power in the Hush House. In each plot the middle curve is the mean spectrum while the upper and lower curves represent the extreme values at each frequency

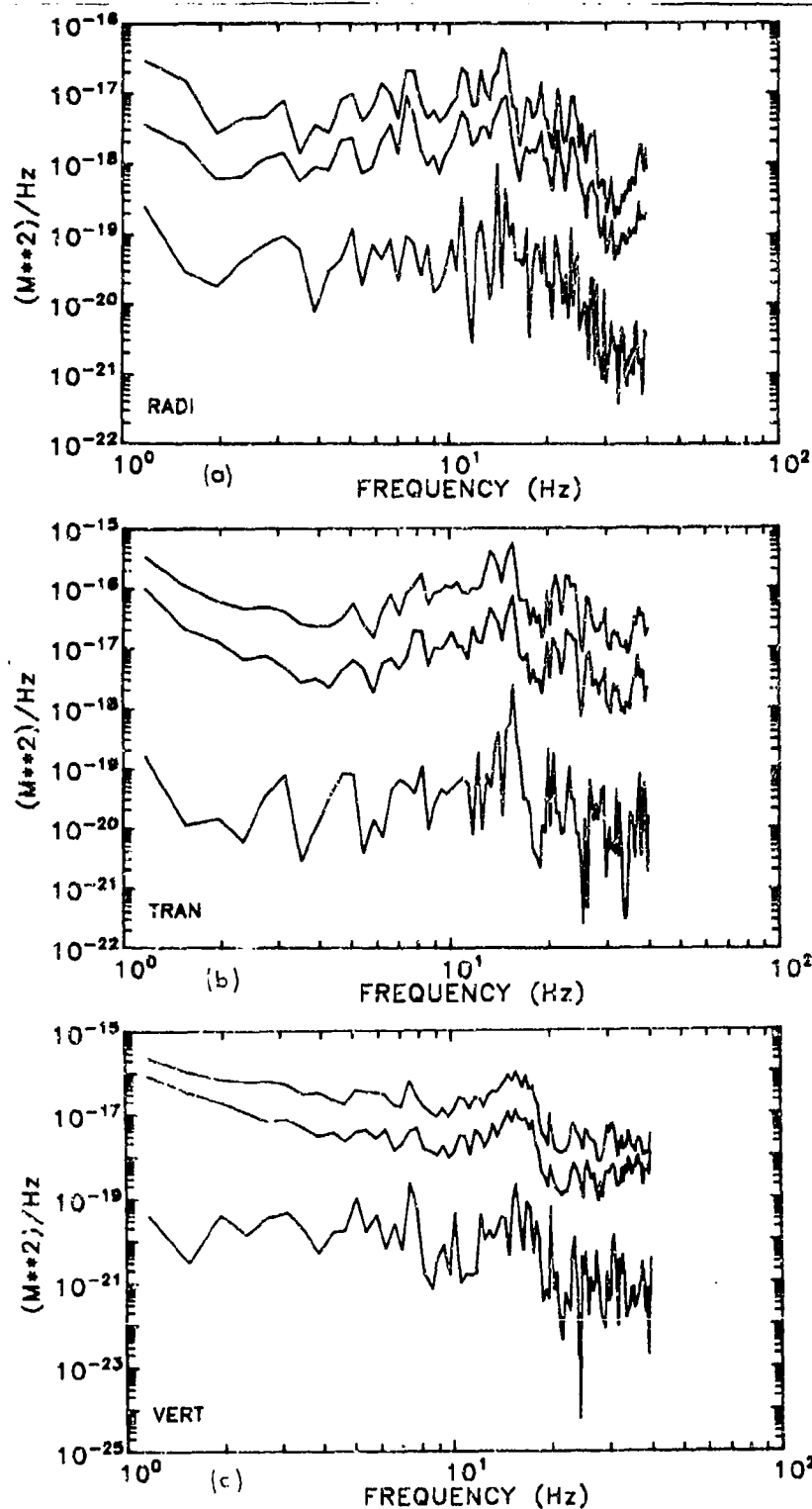


Figure 25. (a) Radial, (b) Transverse, and (c) Vertical Displacement Power Spectral Density Plots for Site 2 With an F-4 in Afterburner in the Hush House. In each plot the middle curve is the mean spectrum while the upper and lower curves represent the extreme values at each frequency

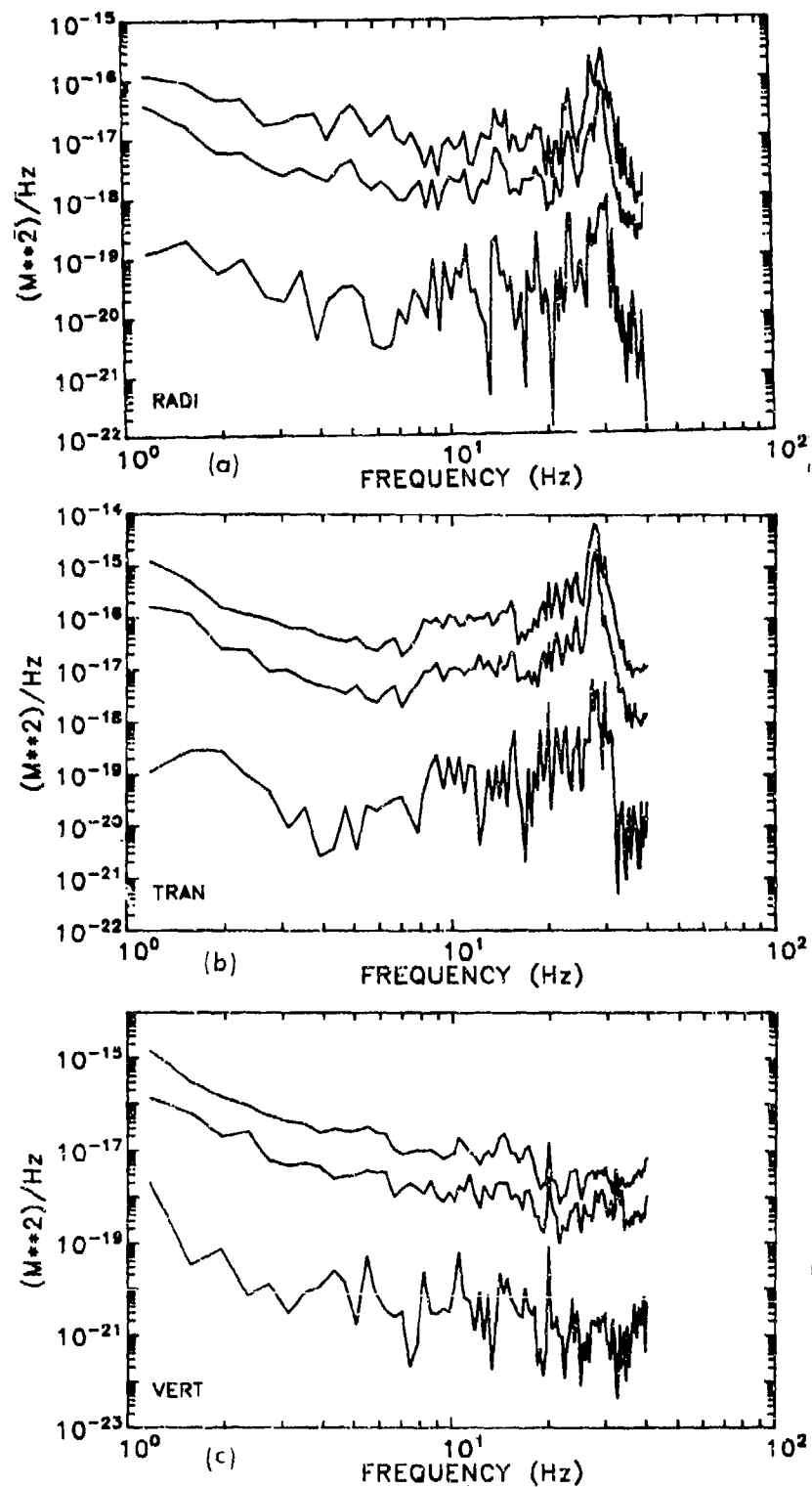


Figure 26. (a) Radial, (b) Transverse, and (c) Vertical Displacement Power Spectral Density Plots for Site 2 With an F-15 in Military Power in the Hush House. In each plot the middle curve is the mean spectrum while the upper and lower curves represent the extreme values at each frequency (Transducer on IMU pedestal)

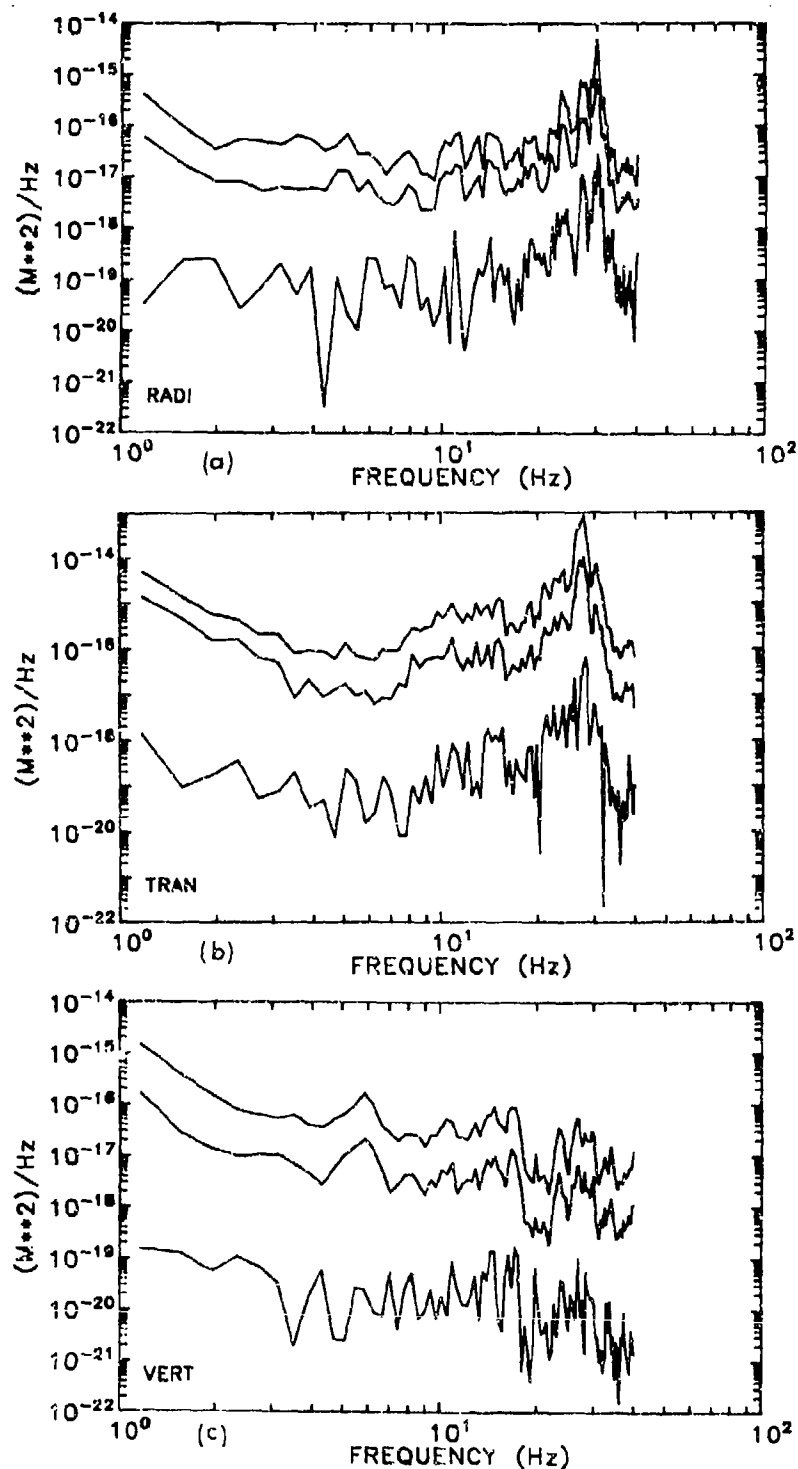


Figure 27. (a) Radial, (b) Transverse, and (c) Vertical Displacement Power Spectral Density Plots for Site 2 With an F-15 in Afterburner in the Hush House. In each plot the middle curve is the mean spectrum while the upper and lower curves represent the extreme values at each frequency (Transducer on IMU pedestal)

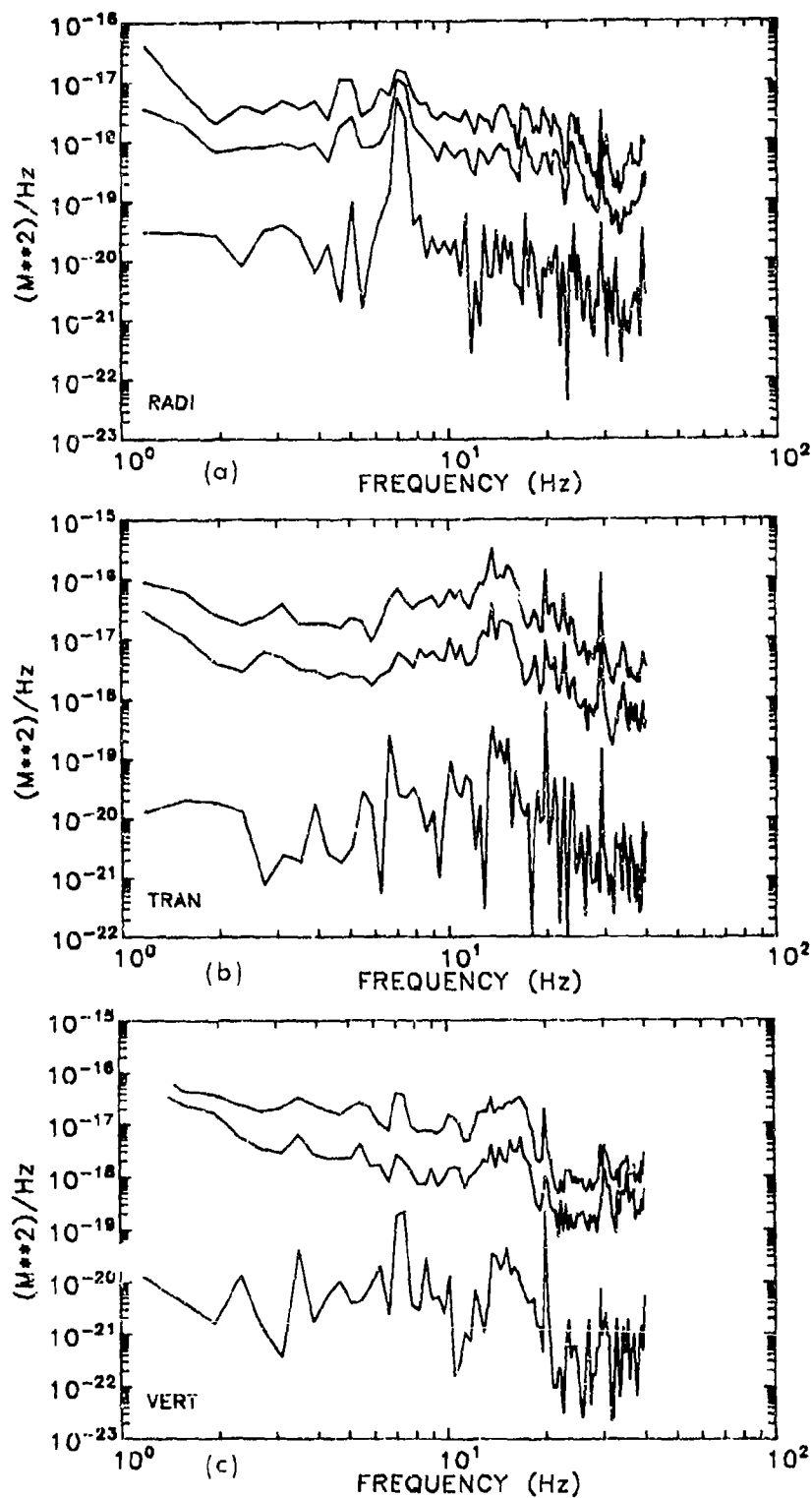


Figure 28. (a) Radial, (b) Transverse, and (c) Vertical Displacement Power Spectral Density Plots for Site 2 With an F-16 in Military Power in the Hush House. In each plot the middle curve is the mean spectrum while the upper and lower curves represent the extreme values at each frequency

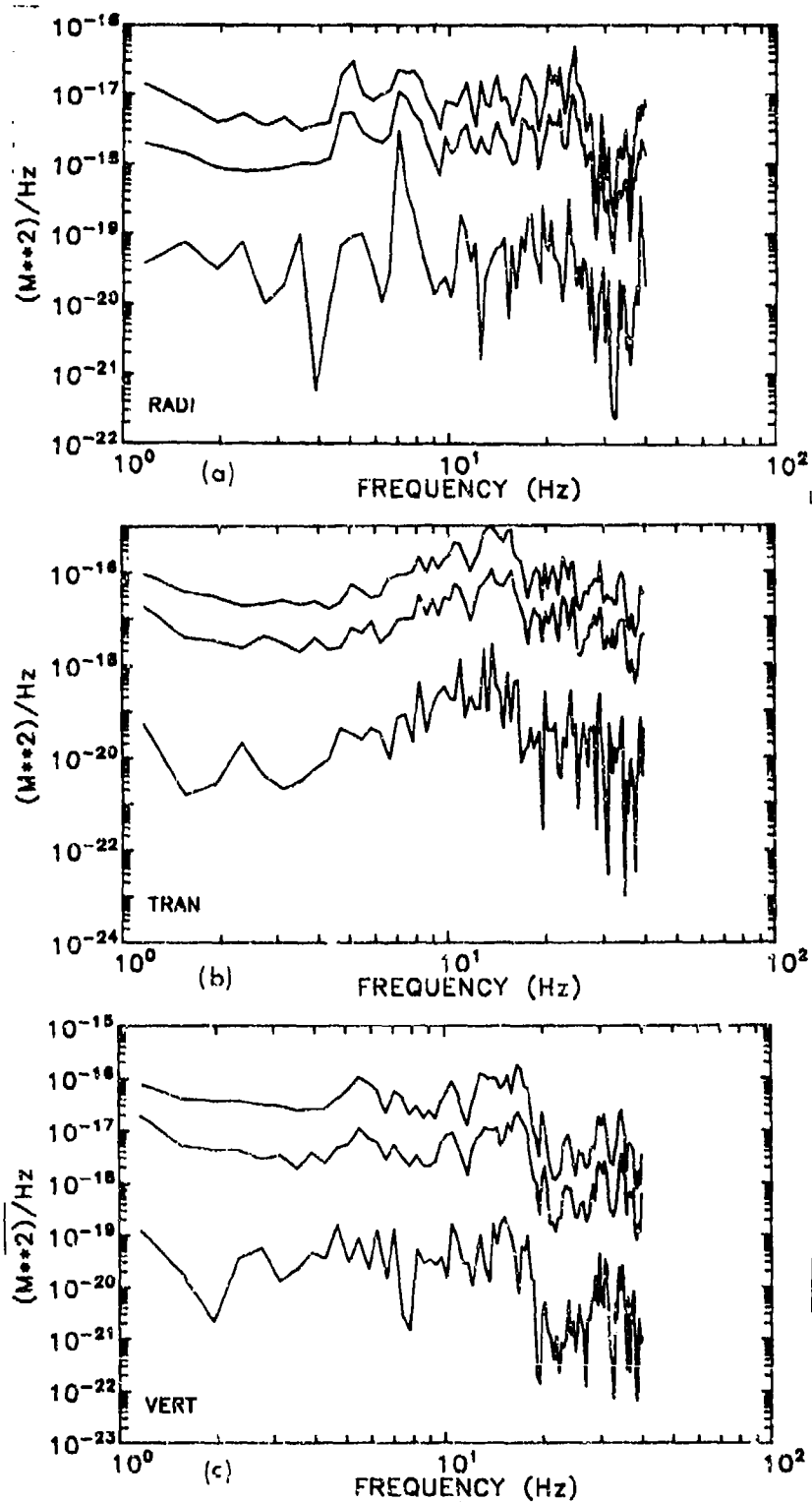


Figure 29. (a) Radial, (b) Transverse, and (c) Vertical Displacement Power Spectral Density Plots for Site 2 With an F-16 in Afterburner in the Hush House. In each plot the middle curve is the mean spectrum while the upper and lower curves represent the extreme values at each frequency

These spectra demonstrate a significant point in terms of the development of siting criteria for the Hush House. A large percentage of the displacement energy in this structure is driven by the low frequency, secondary, lobe of the Hush House infrasonic source. Although the main lobe of the source has more total power, the compliance of the structure is greater at the lower frequencies. Thus, the low frequency loads are more efficient in exciting the structure than are the stronger high frequency pressures. As the fundamental modes of any substantial structure will likely be below 10 Hz, the secondary lobe of the Hush House source can play a dominant role in determining the motion environment within any structure.

From Figures 26 and 27, it is apparent that the motions on top of the IMU pedestal reflect the horizontal natural modes of the pedestal itself, predominantly 27 and 30 Hz. As would be expected, the vertical motion is essentially the same as those found for the floor slab for the F-16. Conversely, it is noted that these same peaks appear in the floor slab data but at much lower relative levels. For the floor slab, these peaks represent the energy re-radiated, or backscattered, into the slab by the vibrations of the IMU pedestal. Although not of large amplitude, the interaction of the IMU pedestal and the floor slab demonstrate the complexity of causative factors of the motion environment at any given site.

Finally, admittance terms were estimated for site 1 and site 2 at slab level and are presented in Figures 30 and 31. The admittance is defined as the frequency dependent ratio of the induced velocity to the causative pressures. For this analysis, the driving pressures were assumed to be those recorded at site 5B. Although site 5C is the closest pressure transducer to the Avionics Building, the spectral nulls noted at this site are not believed to be represented in the actual pressure loads on the structure.

As normal functions in the Avionics facility were not stopped during the data recording periods, it can be assumed that some of the content of each signal is uncorrelated with the Hush House acoustic source. To reduce the effect of these "stray" signals, the presented admittance functions were obtained by averaging the functions estimated for each aircraft and power setting. In fact, it was found that the individual admittance estimates were highly consistent at least in the bandwidth of 1 to 30 Hz and the averaging process had only a small effect on the final plots. This consistency suggests that the presented admittance functions are predominantly the result of Hush House induced loads and are not contaminated by other, unknown sources.

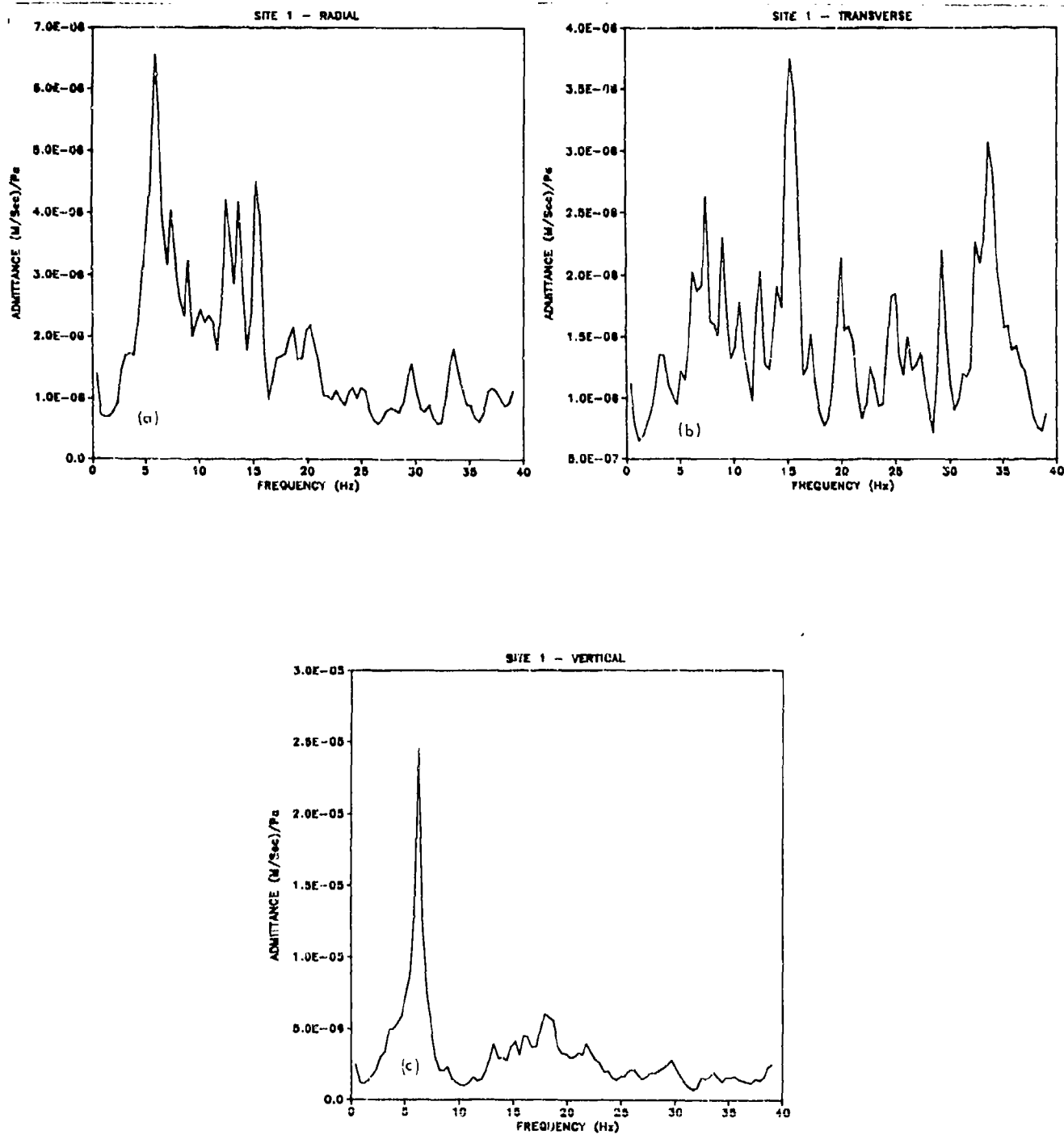


Figure 30. (a) Radial, (b) Transverse, and (c) Vertical Admittance Functions for Site 1 in the Avionics Building

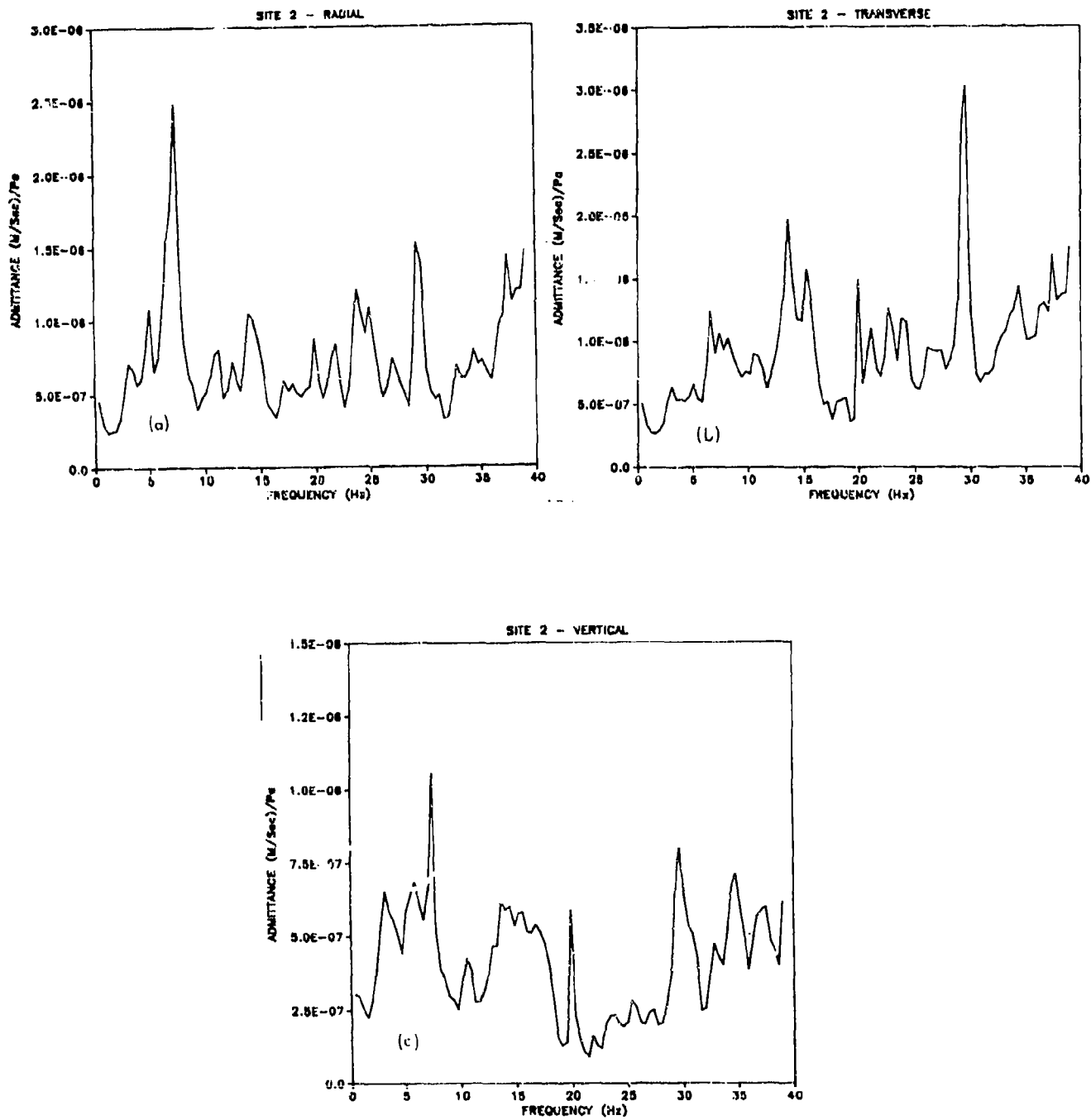


Figure 31. (a) Radial, (b) Transverse, and (c) Vertical Admittance Functions for Site 2 in the Avionics Building

The peaks in the admittance function can be related to the resonant modes of the structure and the relative amplitudes of the peaks demonstrate the ease with which a Hush House type source (collocated with the existing Hush House) can excite these modes. A good example of this is shown in Figure 31 with the peak occurring just below 30 Hz. Based on spectra and admittances evaluated for the top of the IMU pedestal, this peak can be associated with backscattered energy from the IMU pedestal. The amplitude of the peak is high because the Hush House acoustic source is relatively weak at this frequency. The actual motion amplitude associated with this frequency is, however, relatively low.

These plots can be used to predict the motions at each site for a Hush House type source collocated with the existing Hush House and given the pressures that would be observed at site 5B. More importantly, however, they provide some insight into the potential effect of altering the Hush House source, one proposal that has been presented to reduce the vibration environment impact of the Hush House.¹¹ At present, the source alteration proposals have concentrated on altering the air flow through the augmentor tube, presumably responsible for the main lobe of the Hush House infrasonic source. This would be done by introducing vanes inside the Hush House to produce more turbulent flow in the augmentor tube. This is expected to raise the center frequency of the main lobe of the acoustic source. Assuming the secondary lobe is the result of a jet type source associated with the air intakes, it is not clear that the existing proposal should have any effect on the position or amplitude of this lobe. (It should be noted that the people proposing this solution have an alternative hypothesis for the generation of Hush House infrasonics and an alternative explanation of the secondary lobe.¹¹

It is apparent from the admittances shown in Figures 30 and 31 that significant contributions to the motion environment at these sites result from loading at frequencies near the secondary lobe, around 5 Hz. In addition, resonances above 20 Hz could also make significant contribution, particularly at site 2. As most structures will have fundamental modes below 10 Hz, it should be apparent that the secondary lobe of the infrasonic source will play a significant role in defining the induced motion environments in these structures. While alteration of the source is one potential solution to the vibro-acoustic problems associated with Hush House operation, the interplay of the emissions and structural responses must be considered over a wide range of frequencies. It is apparent that modification of only the main lobe will not fully resolve these problems.

5.4 Building 221

In Building 221, velocity transducers were located on the floor slab near the footing of the central column on the Hush House side of the structure, site 3, and at the intersection of this column with a cross-beam, approximately 4.6 meters above ground level, site 4. The building is a pre-engineered, hangar-type structure located approximately 80 meters from the Hush House exhaust deflector. The primary concern at this site was for the safety of the structure. After the Hush House was installed, sheet metal siding on the building had loosened.⁷ As criteria for safety of structures are in terms of velocity, see Table 4, the analysis for these sites was done in terms of velocity.

The instrumentation used in this study proved to be too sensitive for the motion levels experienced at site 4 and much of the data exceeded the dynamic range of the equipment, particularly on the radial components. In addition, and apparently as a result of severe vibrations, both data recorders at this site operated intermittently. Thus, for operations in afterburner much shorter data segments were available for analysis than at other locations; as short as 32 seconds. In spite of these problems, it was possible to recover information on the vibration environment at this location.

5.4.1 TIME DOMAIN ANALYSIS

Tables 7a and 7b show the statistics for the velocity environments at sites 3 and 4. It is apparent that the environment in this structure is especially severe. This is explained by the close proximity of the structure to the Hush House and by the very flexible nature of the building. As would be expected, the radial components of motion are most severely effected at this site.

At least one component, usually the radial, was severely clipped for all runs in afterburner and most runs at military power. However, for the F-4 at military power, unclipped data was collected and used to evaluate the motion environment for afterburner runs. For each unclipped record at this site, a site specific PSD response function was evaluated, analogous to the admittance function discussed in Section 5.3.2. These were formed using the appropriate pressure spectrum from site 5A as a reference. An estimate of the velocity rms value for any other run could be made by multiplying the response function by the appropriate pressure amplitude spectrum, as recorded at site 5A, and applying Parseval's Theorem. When the observed data was clipped, rms values were estimated in this manner, and are given in Table 7b. The method was checked by calculating rms levels for which unclipped data had been collected and was found to provide estimated values in close agreement with the observed data.

Table 7a. Statistics of the Observed Motion Environment in Building 221
(Site 3)

Aircraft	Power Level	Comp	Full Distribution		1-Second Window Distributions		Max. Observed Velocity (in 10^{-5} m/sec)
			rms Level (all in 10^{-5} meters/sec)	Normal 0.001% Exceed- ence Level	Normal 0.001% Exceed- ence Level	Extreme Type I 0.001% Exceed- ence Level	
F-4	MIL	R	0.366	1.132	1.519	1.847	1.596
		T	0.229	0.706	0.938	1.144	1.190
		V	0.064	0.197	0.260	0.305	0.288
	AB	R	1.019	3.149	4.030	4.938	4.116
		T	0.621	1.920	2.469	3.002	2.352
		V	0.157	0.485	0.637	0.770	0.651
F-15	MIL	R	0.567	1.753	2.269	2.705	2.358
		T	0.359	1.110	1.354	1.622	1.270
		V	0.104	0.321	0.412	0.491	0.418
	AB	R	2.062	6.372	8.809	10.839	8.867
		T	1.110	3.439	4.804	5.988	4.617
		V	0.292	0.903	1.095	1.282	0.992
F-16	MIL	R	0.691	2.135	2.864	3.506	2.958
		T	0.420	1.296	1.723	2.121	1.928
		V	0.103	0.318	0.422	0.508	0.492
	AB	R	2.323	7.178	8.846	10.610	8.277
		T	1.260	3.890	5.223	6.439	5.142
		V	0.320	0.988	1.315	1.599	1.297

Table 7b. Statistics of the Observed Motion Environment in Building 221
(Site 4)

Aircraft	Power Level	Comp	Full Distribution		1-Second Window Distributions		Max. Observed Velocity (in 10^{-3} m/sec)
			rms Level (all in 10^{-3} meters/sec)	Normal 0.001% Exceed- ence Level	Normal 0.001% Exceed- ence Level	Extreme Type I 0.001% Exceed- ence Level	
F-4	MIL	R	0.696	2.151	2.052	2.282	1.931
		T	0.379	1.171	1.277	1.483	1.188
		V	0.144	0.445	0.539	0.642	0.510
	AB	R*	1.1	3.4	4.4	5.2	-
		T	0.691	2.135	1.758	1.933	1.651
		V	0.318	0.983	1.302	1.571	1.385
F-15	MIL	R*	0.88	2.7	3.5	4.2	-
		T	0.438	1.354	1.544	1.832	1.406
		V	0.135	0.417	0.534	1.642	0.492
	AB	R*	2.9	9.0	11.5	13.8	-
		T*	1.7	5.3	6.8	8.1	-
		V*	0.58	2.1	2.7	3.2	-
F-16	MIL	R*	0.90	2.8	3.6	4.3	-
		T	0.537	1.659	1.784	2.077	1.585
		V	0.205	0.634	0.823	0.994	0.862
	AB	R*	2.9	9.0	11.5	13.8	-
		T*	1.7	5.3	6.8	8.1	-
		V*	0.71	2.2	2.8	3.4	-

* NOTE: Due to severe clipping of the data, the statistics for the indicated channels are estimated by procedures given in the text.

The 0.001 percent exceedence level for the full distribution can be interpreted as the level reached, on average, twice in every 10 sec of running time; once with a positive sense and once negative. At site 4, the vector sum velocity at this probability level is over 0.01 m/sec. Referring to Table 4, it can be seen that the EPA recommends that stress checks be performed on structures with vibrations exceeding this level. While the 0.001 percent extreme value level is below the 0.025 m/sec level usually assumed for the onset of structural damage it does approach this critical criterion. As runs in afterburner would typically have durations exceeding 10 sec, the extreme value level is a more realistic estimate of the level expected to be attained during any afterburner run.

The recorded vibration levels increase significantly from site 3, located on the floor slab, to site 4, approximately half way up the wide wall of Building 221. It can be anticipated that this trend will continue as one moves higher on the wall. At the roof line, significantly higher level motions than those found at site 4 should be anticipated.

It can only be concluded that the long term safety of this structure is in question. While the level of motions appear to be below that expected for the onset of major structural damage (0.1 m/sec), as long as the Hush House is in operation, the structure will experience repeated vibrations at a level having some potential to initiate structural fatigue. It is recommended at a minimum that this structure undergo periodic inspections for any signs of reduced load bearing capacity of the structural elements.

5.4.2 SPECTRAL ANALYSIS

Due to the amount of clipped data at these sites, only velocity PSD plots for the F-4 in military power are shown for these two sites (Figures 32 and 33). As can be seen from the plots and from Tables 7a and 7b, the motions in Building 221 are dominated by the radial component, which, in turn, is dominated by energy in three general bands centered at about 5, 15 and above 25 Hz. The relatively high levels seen in the upper band were unexpected due to the weakness of the driving force at these frequencies and the generally lower responsiveness of structures at higher frequencies. However, these resonances are also apparent in the noise data, Figure 34, and appear to be real. It is likely that these resonances are related to the vibration of sub-elements of the structure, such as the beams, as contrasted to the motion of the integrated structure. In terms of the structural safety criteria, however, this distinction is not relevant.

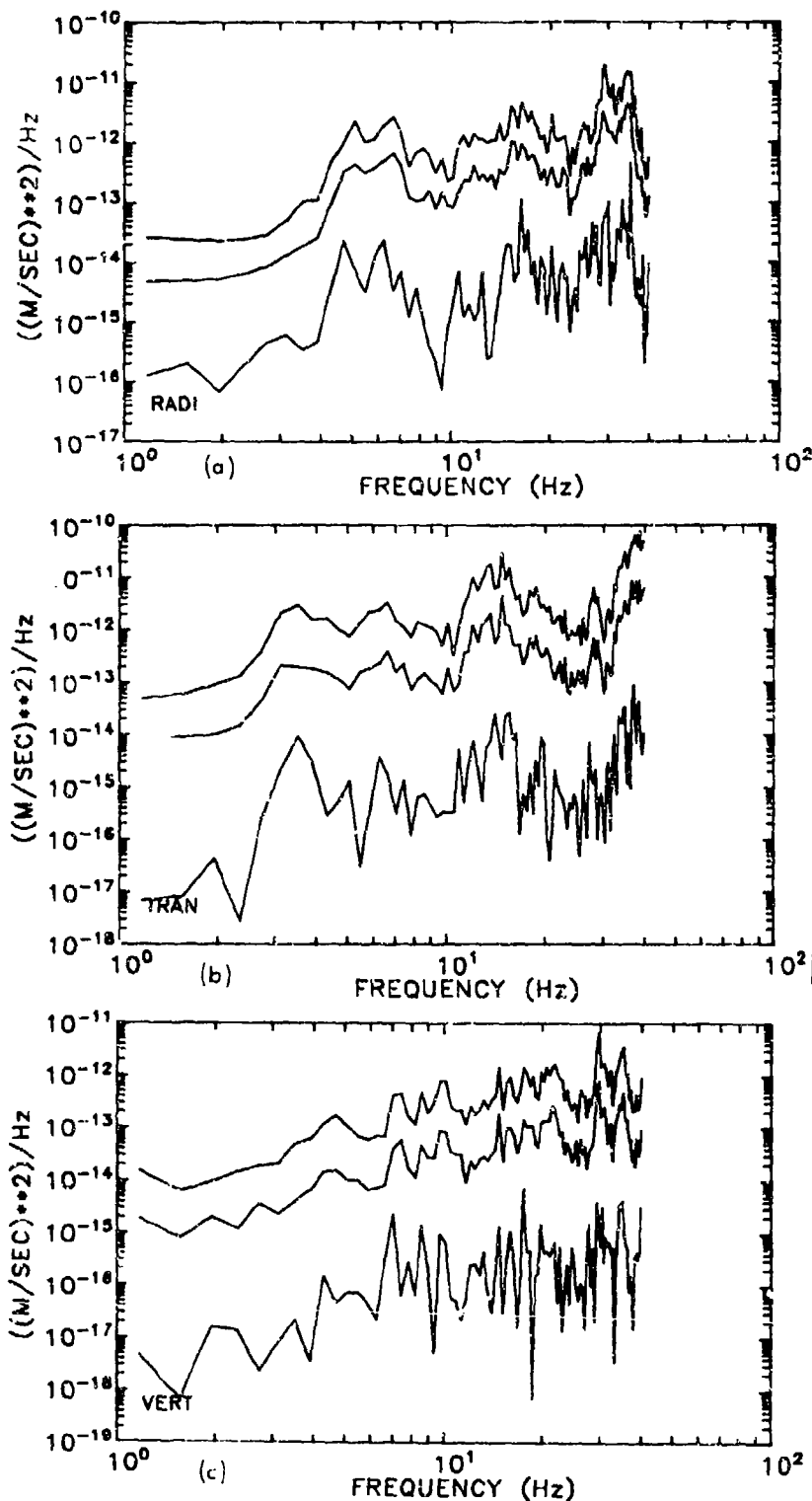


Figure 32. (a) Radial, (b) Transverse, and (c) Vertical Velocity Power Spectral Density Plots for Site 3 With an F-4 in Military Power in the Hush House. In each plot the middle curve is the mean spectrum while the upper and lower curves represent the extreme values at each frequency

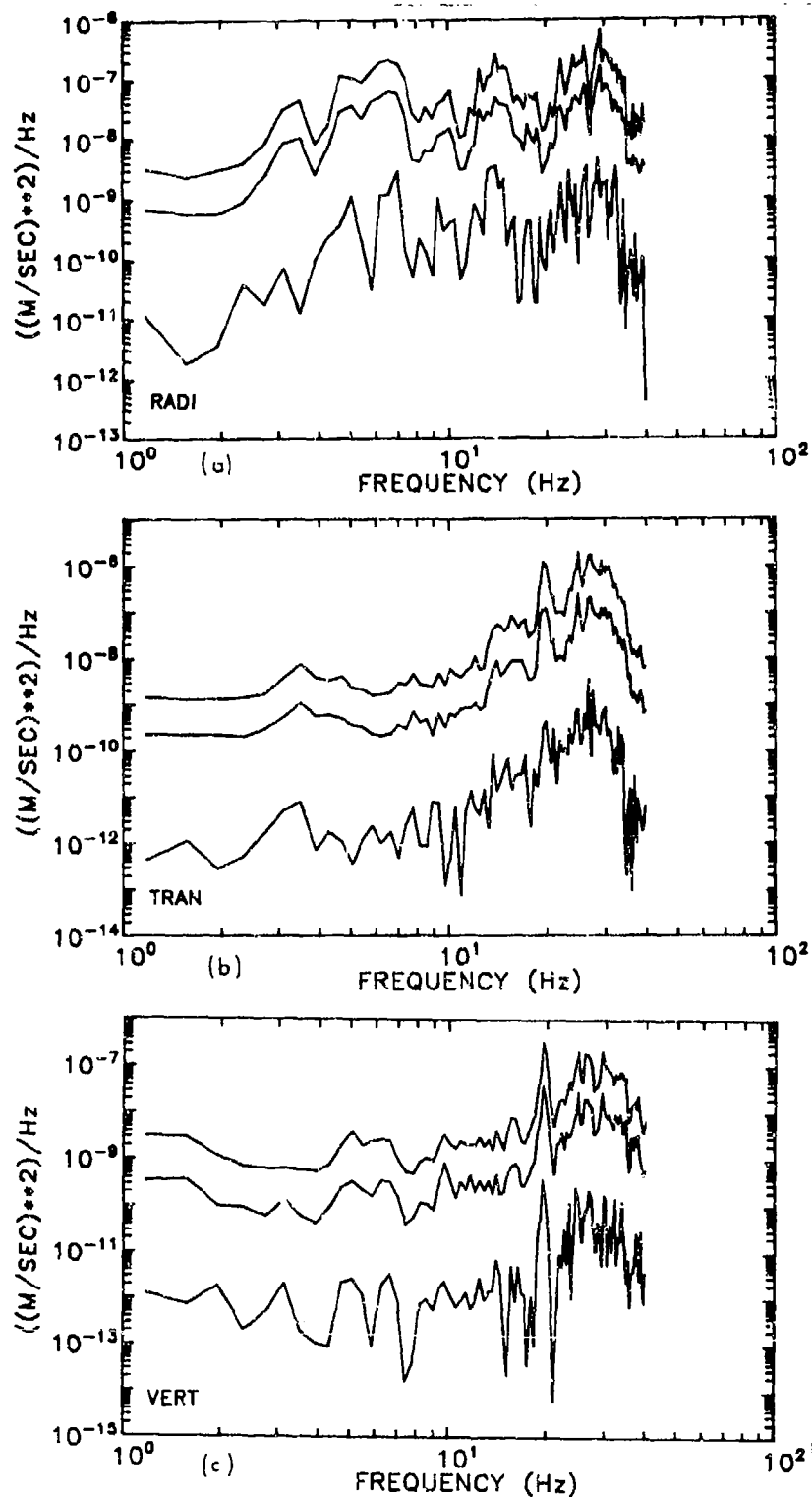


Figure 33. (a) Radial, (b) Transverse, and (c) Vertical Velocity Power Spectral Density Plots for Site 4 With an F-4 in Military Power in the Hush House. In each plot the middle curve is the mean spectrum while the upper and lower curves represent the extreme values at each frequency

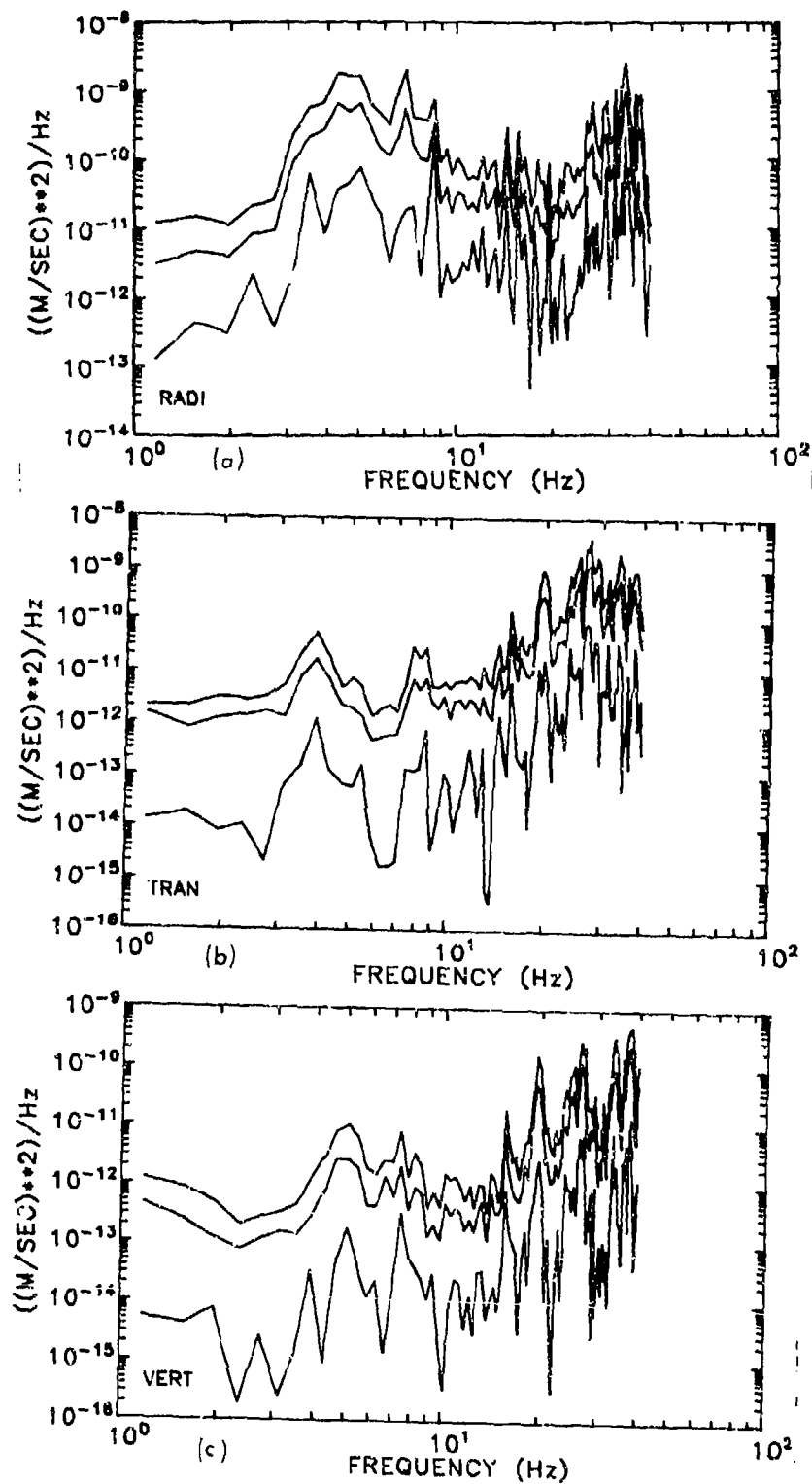


Figure 34. (a) Radial, (b) Transverse, (c) Vertical Velocity Power Spectral Density Plots for a Noise Sample at Site 4. In each plot the middle curve is the mean spectrum while the upper and lower curves represent the extreme values at each frequency

The estimated admittance functions, based on the pressures observed at site 5A, are given in Figures 35 and 36. They all demonstrate the highly responsive nature of Building 221 at frequencies above 20 Hz. The lack of coherency at higher frequencies between the admittances at site 3 and 4 suggests the localized nature of the response. Strong excitations are seen below 20 Hz, particularly at site 4, and are significant contributors to the motion at this site. Analysis of the motions at site 4 bandpassed over 0.8 to 25 Hz show lower motions but with amplitudes still sufficiently high to warrant stress checks.

These admittance functions demonstrate another fact concerning the potential alteration of the source to alleviate the Hush House vibration problems. The higher frequency responses noted in these plots are typical for minor structural elements such as siding or wall partitions. If the Hush House source were altered by driving the primary lobe up in frequency, then the vibrations in this structure, as just one example, would be intensified. Alteration of the source might merely substitute the problem of general structural vibration for more intense vibration in sub-elements. As the higher frequency vibrations would result in acoustic interference with human activities, due to rattling of walls and similar problems, the apparent negative impact of the Hush House acoustic source could become more widespread than at present.

5.5 Proposed Building Site

The proposed site for a new avionics building, as required under the present Hush House siting criteria, would be located across the road from the existing facility, approximately at site 7 in Figure 2. Seismic measurements were made during all aircraft runs and a survey was conducted to determine the effect of interstate 540 at the site.

The value of this data for future planning is very limited. For the measurements during the aircraft runs it should be noted that the dominant coupling with the Hush House acoustic source is directly with the structure and there is unlikely to be significant ground transmission. Thus, measurements at this site cannot reflect the major anticipated source of vibration. Further, any construction at this site will greatly disturb the soil column and modify the local response and transmission characteristics.

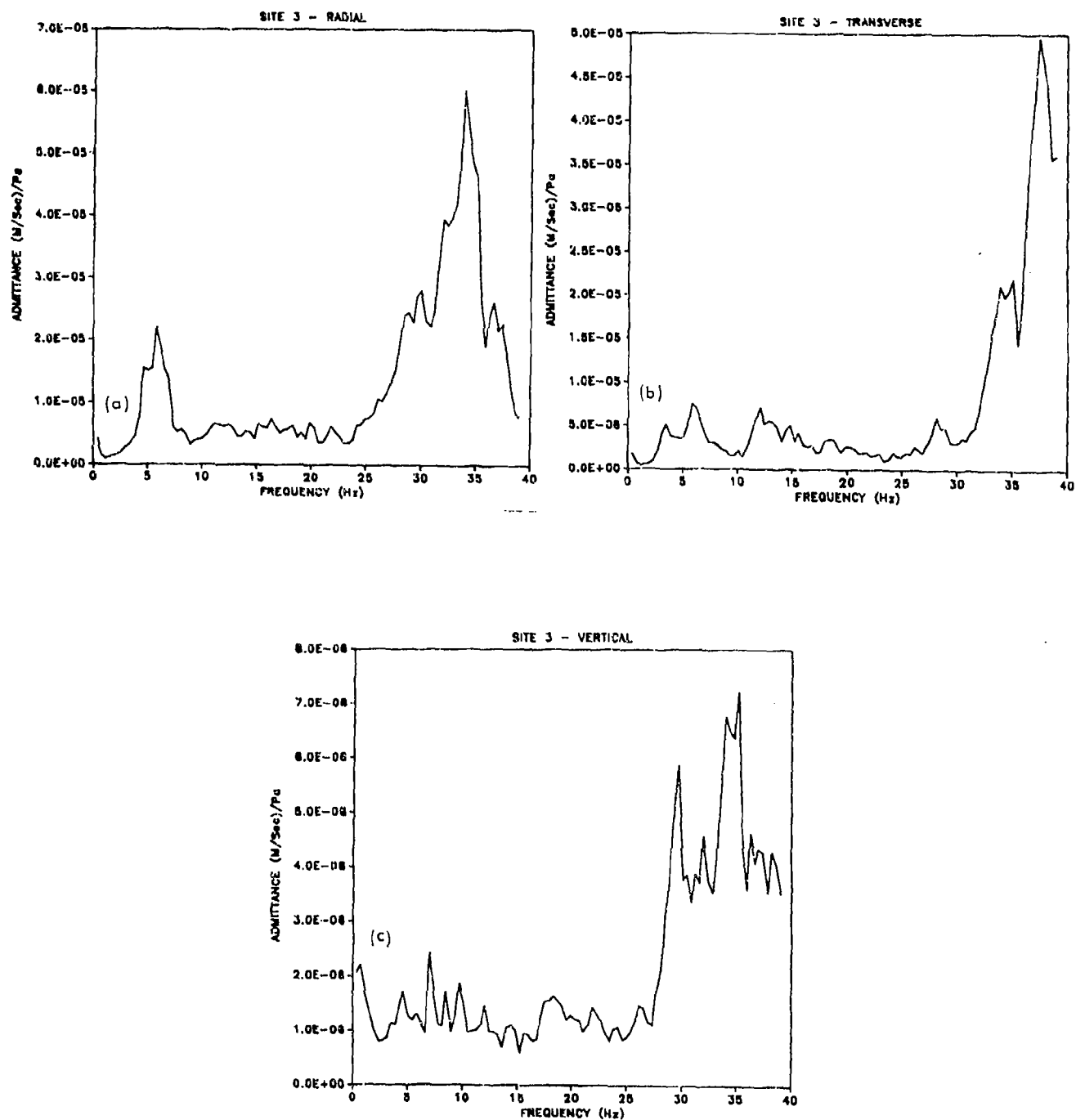


Figure 35. (a) Radial, (b) Transverse, and (c) Vertical Admittance Functions for Site 3 in Building 221

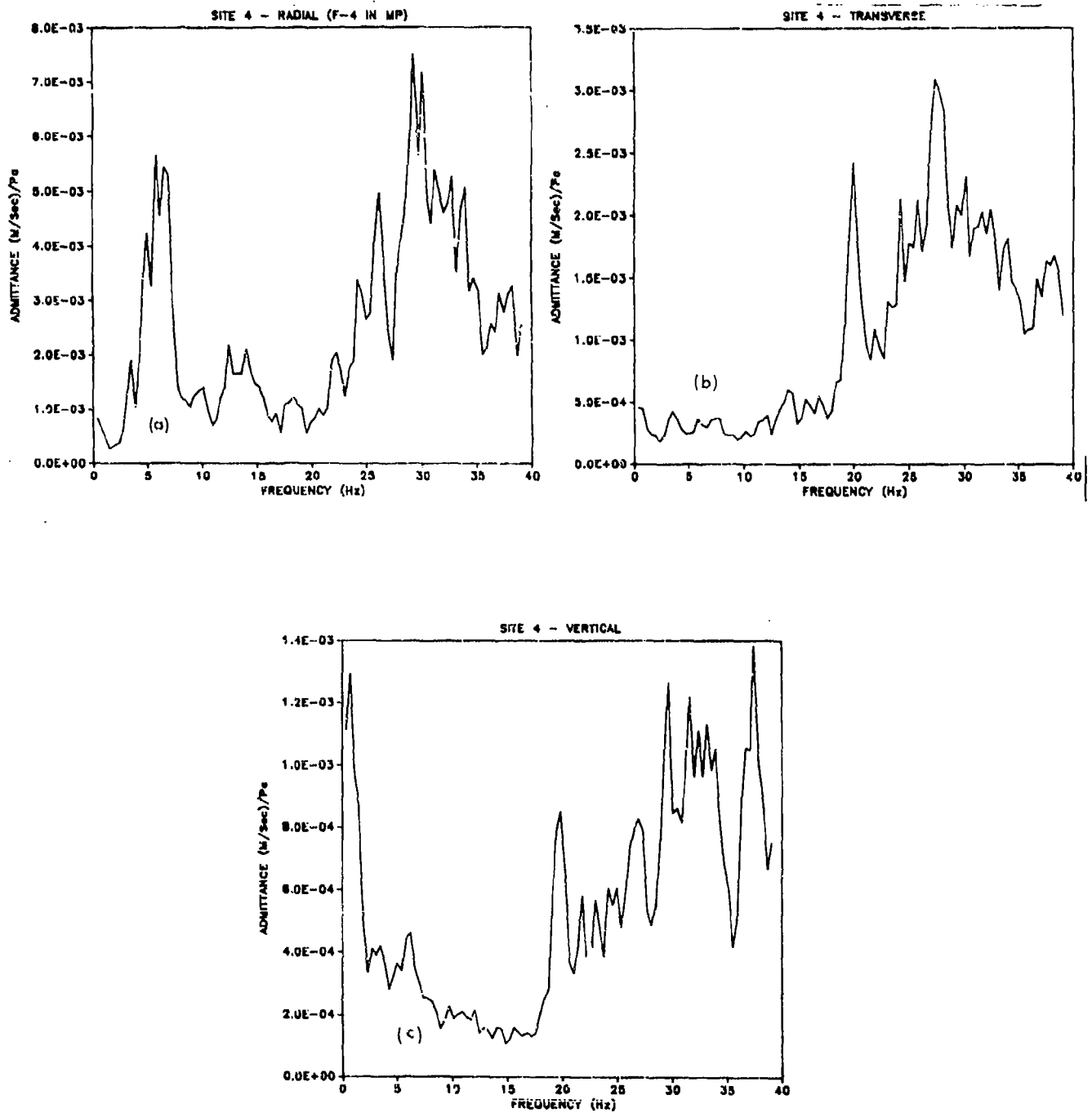


Figure 36. (a) Radial, (b) Transverse, and (c) Vertical Admittance Functions for Site 4 in Building 221

5.5.1 TIME DOMAIN ANALYSIS

Table 8 gives the statistics of the motion environment as observed at site 7 during aircraft runs and, for sites 7 and 8, for the highway noise survey. It appears from this data that a correlation does exist between the measured levels at site 7 and Hush House operations. Noise levels during Hush House operations are about twice as high as ambient conditions indicated during the highway noise survey. It is, however, also apparent that the correlation is not the result of direct coupling of the acoustic signal from the Hush House and the ground.

If direct coupling were significant then the dominant motions should be recorded on the vertical component. At this site the transverse component is the most active. This suggests that the coupling between the acoustics and the ground is through a second source such as trees. The identity of the secondary source cannot be confirmed without further studies.

Figure 37 shows a sample of the velocity time history recorded during runs of an F-16 in afterburner. The strongly resonant nature of the vibrations recorded at site 7 is evident in these traces. One relevant point, however, is the occurrence of a strong transient on the transverse component just before the 4-sec point on the record. This transient does not appear on the other components of motion. Transients of this type are the largest signals detected at site 7 during both the Hush House runs and the highway noise survey but were not recorded at site 8. The source of these transients remains unidentified but is likely to be wind generated noise from several trees located within about 20 meters of site 7. Again, this cannot be confirmed solely from the available data.

The highway noise survey shows that displacement rms and absolute peak noise levels are lower at site 8, close to the Interstate, than at site 7. As during Hush House runs, it appears that ambient conditions at site 7 are dominated by wind generated noise. The observed displacements at site 7 during the highway noise study are seen to be about one-half of the level observed during runs of the F-15 and F-16 in afterburner. However, as the motions during Hush House runs appear to be dominated by a secondary source, the significance of this fact is low. If one assumes that the observed displacements would be typical of the floor slab displacements after construction, then the levels of motion observed due to highway noise at site 7 are essentially two orders of magnitude below the EPA criterion for critical working areas. The levels are comparable to ambient conditions measured at other sites.

Table 8. Statistics of the Observed Displacement Motion Environment at Sites 7 and 8

Aircraft	Power Level	Comp	Full Distribution		1 Second Window Distributions		Max. Displacement (in 10 ⁻³ meters)	
			rms Level (all in 10 ⁻⁸ meters)	Normal 0.001% Exceedence Level	Normal 0.001% Exceedence Level	Extreme Type I 0.01% Exceedence Level		
Site 7:								
F-4	MIL	R	0.757	2.339	3.343	4.370	3.592	
		T	1.649	5.097	7.262	9.684	8.328	
		V	0.485	1.499	2.014	2.585	2.401	
	AB	R	1.312	4.055	6.410	8.606	6.348	
		T	2.270	7.013	11.147	15.263	12.094	
		V	0.725	2.240	3.286	4.208	3.274	
	F-15	MIL	R	1.337	4.132	6.451	8.794	6.944
			T	2.367	7.314	10.778	14.493	10.690
			V	0.468	1.447	2.146	2.770	1.921
AB		R	1.446	4.468	6.021	7.532	5.884	
		T	2.072	6.402	10.173	13.581	10.020	
		V	0.769	2.376	3.144	3.823	2.911	
F-16	MIL	R	1.547	4.781	7.429	10.026	7.738	
		T	3.228	9.974	16.579	22.781	22.005	
		V	0.704	2.176	3.481	4.653	4.253	
	AB	R	1.518	4.999	8.294	11.095	9.076	
		T	3.191	9.860	18.551	26.113	24.430	
		V	0.774	2.393	3.816	4.901	4.356	
	Highway Noise	R	0.918	2.836	4.180	5.717	5.164	
		T	1.767	5.461	8.911	12.422	11.550	
		V	0.463	1.430	2.171	2.934	2.808	
Site 8:								
Highway Noise	R	0.564	1.742	2.955	3.898	3.777		
	T	1.000	3.089	4.730	6.128	4.578		
	V	0.279	0.863	1.419	1.839	1.890		

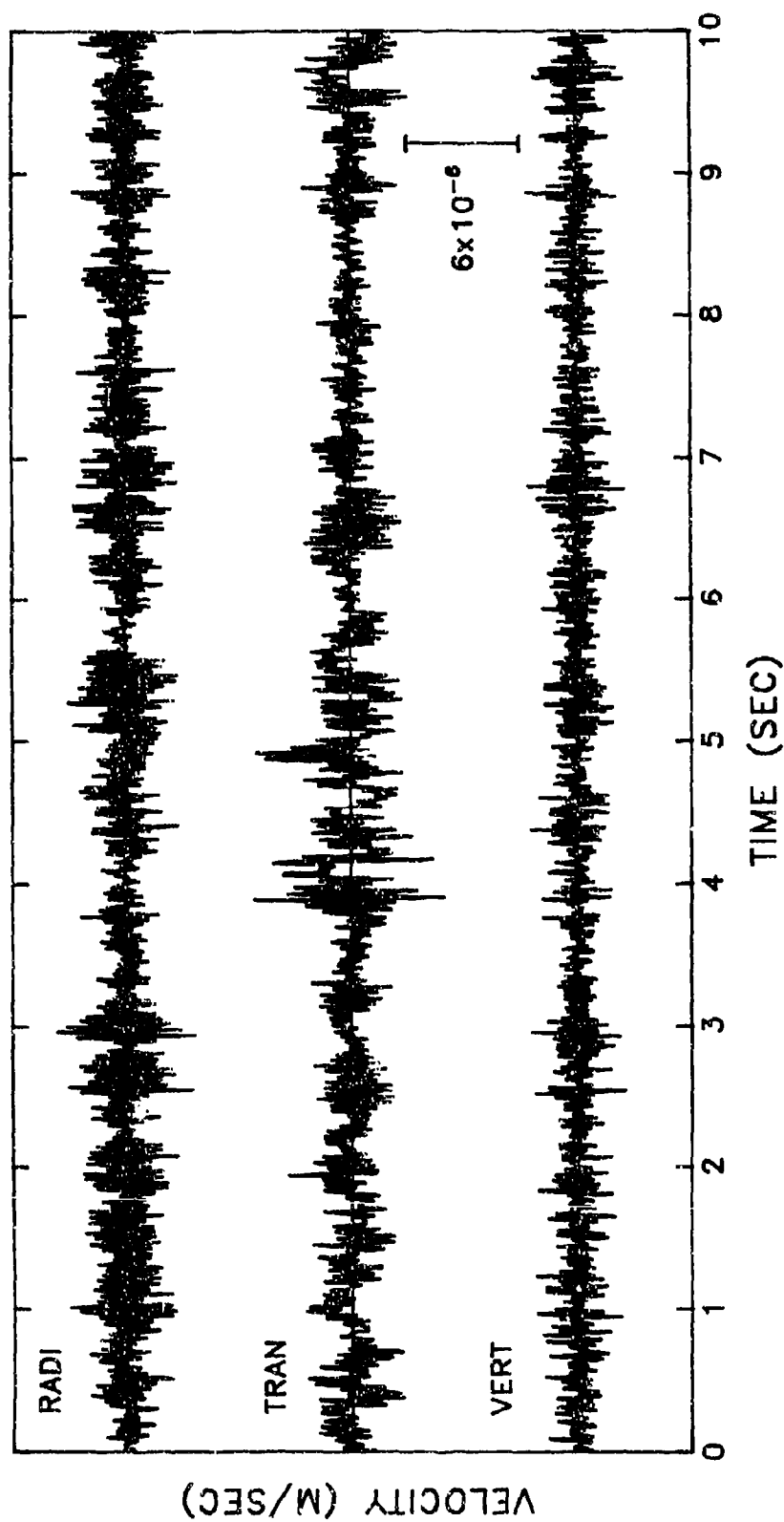


Figure 37. Observed Velocity Time History at Site 7 for an F-16 in Afterburner

5.5.2 FREQUENCY DOMAIN ANALYSIS

Spectral analysis of the data taken at sites 7 and 8 reinforces the conclusions from the time domain analysis. Figure 38 shows the displacement PSDs for an F-16 in afterburner at site 7. The resonance noted in the time domain plot is seen on the radial and transverse component PSDs to occur at about 29 and 22 Hz, respectively and the lack of strong vertical excitation at these frequencies is also seen. With the exception of these peaks, the spectra are typical of seismic noise PSD plots.

Figures 39 and 40 show the PSD plots based on the identical time interval during the highway noise survey at sites 7 and 8. A broad peak in the noise is seen over the frequency band of 15 to 25 Hz. This peak is not observed in spectra at site 7. Traffic generated seismic noise is typically within this band and it can be assumed that the traffic induced displacements are attenuated between sites 8 and 7.¹⁴ At site 7 the resonant peaks noted during Hush House operations persist in the noise data but they are not as strong at site 8. This supports the assumption that they are the result of a secondary source located near site 7.

It should be noted that, in terms of velocity, the higher noise levels are found at site 8. This effect is related to the frequency distribution of the noise. Displacement measurements de-emphasize the high frequencies that are predominant at site 8 while velocity measurements de-emphasize the low frequencies, dominant at site 7.

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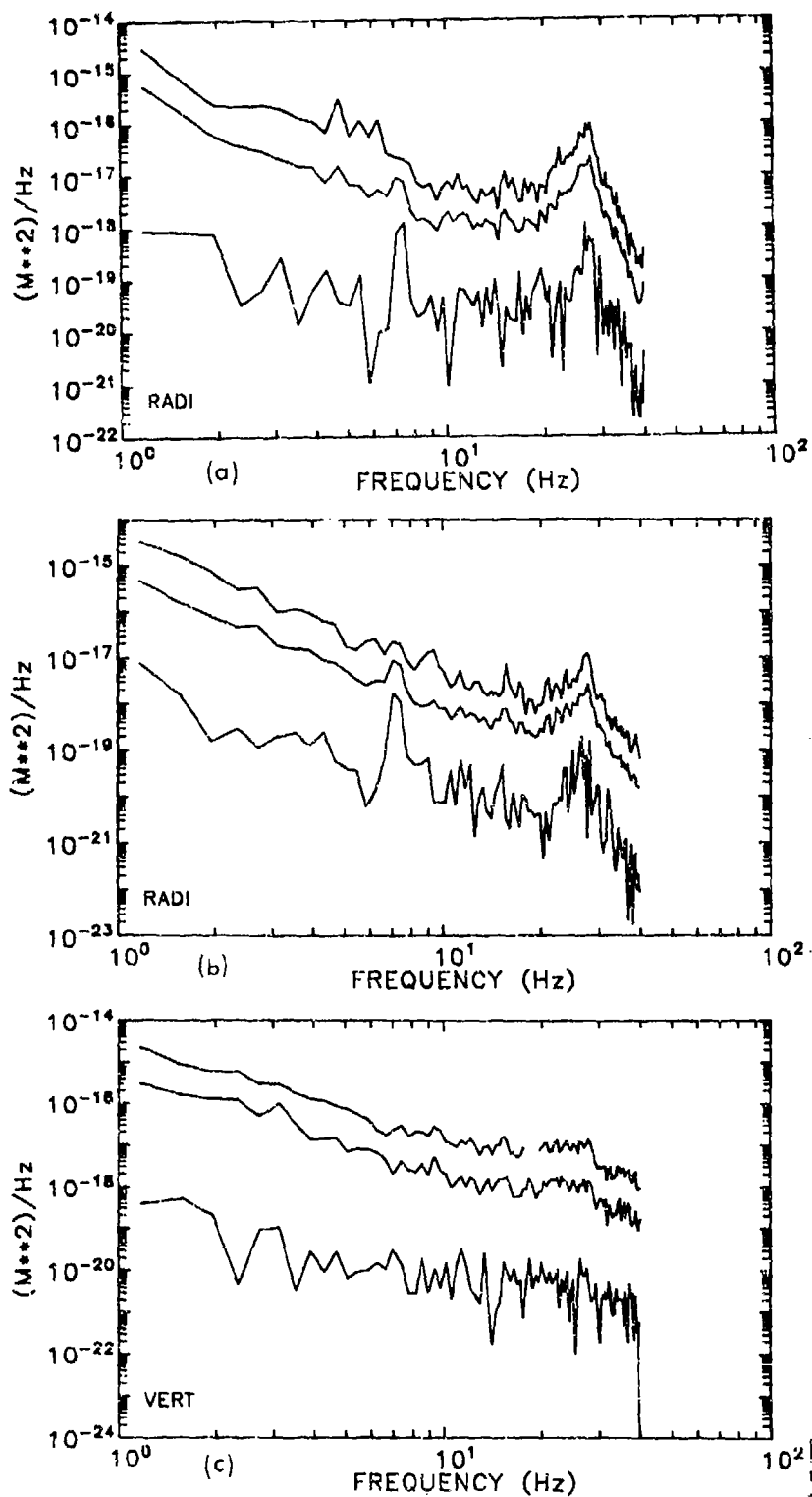


Figure 38. (a) Radial, (b) Transverse, and (c) Vertical Displacement Power Spectral Density Plots for an F-16 in Afterburner at Site 7. In each plot, the middle curve is the mean spectrum, while the upper and lower curves represent the extreme values at each frequency

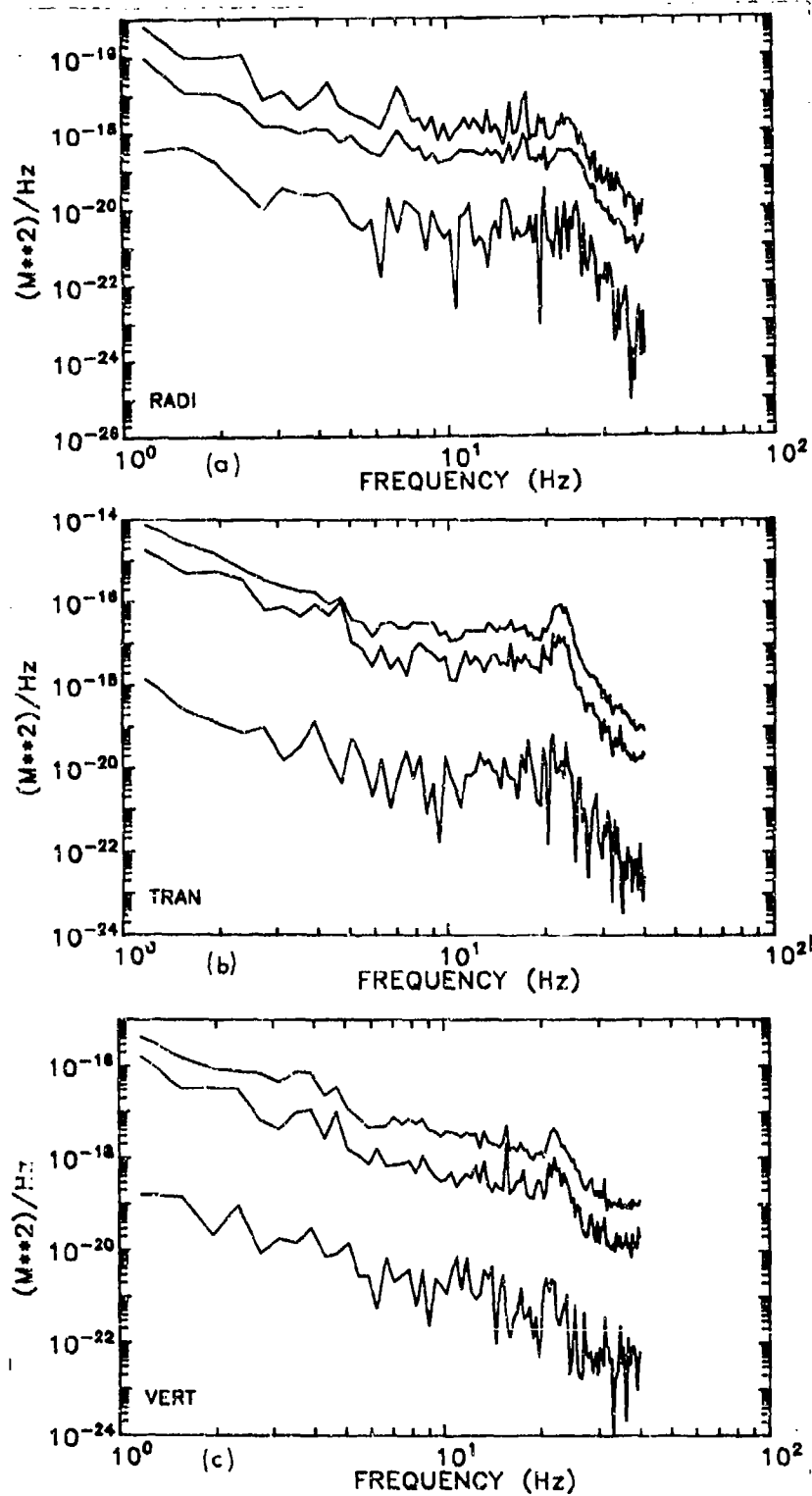


Figure 39. (a) Radial, (b) Transverse, and (c) Vertical Displacement Power Spectral Density Plots for the Highway Noise Study at Site 7. In each plot, the middle curve is the mean spectrum, while the upper and lower curves represent the extreme values at each frequency

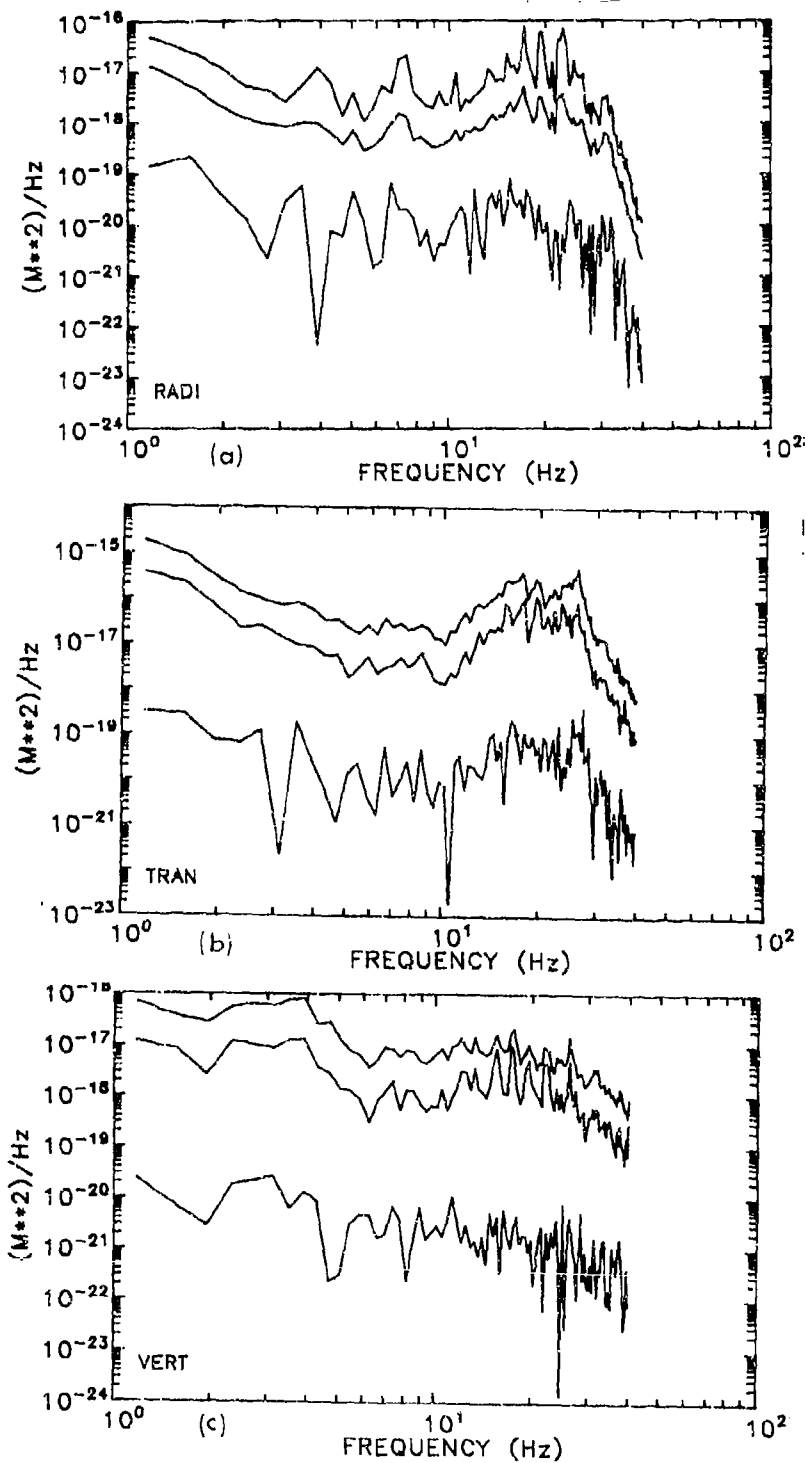


Figure 40. (a) Radial, (b) Transverse, and (c) Vertical Displacement Power Spectral Density Plots for the Highway Noise Study at Site 8. In each plot, the middle curve is the mean spectrum, while the upper and lower curves represent the extreme values at each frequency

6. SUMMARY AND CONCLUSIONS

6.1 Fort Smith Specific Results

In terms of the questions raised by the ANG concerning Hush House operations at the Fort Smith facility, there are three results:

- (1) The motion environment in the existing Avionics Building at Fort Smith will be degraded by Hush House operations with the F-16, but only for operations in afterburner. Present Hush House operations, with the F-4 in afterburner, generate higher motion levels than will the F-16 in military power. While the environment will be adversely impacted during F-16 afterburner runs, it will be significantly below existing EPA criteria for motion sensitive work areas. Further, the levels observed at this site are several orders of magnitude below those capable of damaging the F-16 avionics test benches based on the manufacturer's specifications.
- (2) Building 221 experiences severe motions during all Hush House operations and, in particular, during afterburner runs. The motions in this building are sufficient to warrant concern for the long term safety of the structure. It is highly recommended that some form of periodic inspections be instituted to check the structural elements of Building 221 for fatigue type failure or, alternatively, that the structure be re-sited.
- (3) Finally, the motion environment at the proposed building site, approximated by the location of site 7, is not significantly higher than levels observed at other sites at the ANG facility. As Hush House infrasonics attenuate as $1/R$, the pressure loads at this site are about one-half those at the present avionics structure. A similar building, at this location and with similar orientation relative to the Hush House, should experience induced vibrations proportional to the pressure loads.

6.2 Implications for Hush House Siting

Several implications exist in the results of this study relative to the siting criteria for Hush Houses. First, that the existing 330 meter exclusion zone for motion sensitive facilities is likely to be found to be overly stringent. The present case study provides one example of a structure, essentially picked at random, in which the criterion is too stringent. In fact, using the standard R_0/R scaling law for acoustic far-field pressures, where R_0 is a reference distance and R is the

source radius to the point of interest, and assuming a radially symmetric source, the EPA criterion for a critical work area would not be exceeded unless the Avionics Building was within 25 meters of the Hush House exhaust deflector. This assumes a standard pressure spectrum and a linear relationship between vibrations in the structure and loads. While this calculation cannot, due to the assumptions, be used as a basis for any rational criterion for Hush House siting, it does suggest the lack of a strong scientific basis for the existing criteria.

Alternatively one can look at Building 221. This structure is 89 meters from the exhaust deflector of the Hush House. To reduce the motion levels at site 4 in this structure to levels considered very unlikely to produce structural damages, 0.006 m/sec, would require moving the building out to 145 meters, beyond the 115 meters specified in Table 1. As mentioned earlier, motion levels higher up on the structure are anticipated to be even greater and would require moving the structure further out, well beyond the cited criterion for pre-engineered structures.

In terms of future scientific study on the Hush House problem, three major points should be made:

- (1) The primary fundamental modes of most substantial structures lie below 10 Hz and the motion environment in these structures will be inordinately driven by the secondary lobe of the Hush House infrasonic source.
- (2) A working hypothesis for the structure of the Hush House infrasonic source has been presented. While the hypothesis cannot be ruled out by existing data, much work remains before the hypothesis can be accepted outright. In light of the fact that proposals have been presented to alleviate the infrasonic problems with the Hush House by altering the source, it would seem desirable that one should have a well established understanding of the existing source.
- (3) If the working hypothesis is correct, then the secondary lobe of the Hush House source is the result of a "negative" jet associated with the air intakes of the Hush House. To a large degree it is this jet that will control the motion environment in nearby structures. In turn, this jet is controlled by the velocity of air entering the Hush House through the inlet ducts. As the area of the inlet ducts remains constant, at least in present designs, then the velocity of the air is controlled by the volume of air entering per unit time. The volume of air entering the Hush House is related to two parameters of the engine, its size and power setting. The implication is that as one builds Hush Houses for larger engines, with or without afterburners, the volume of air entering the Hush House

will necessarily increase and the secondary lobe of the source will become increasingly powerful.

The problem of Hush House infrasonics and their effects on the surrounding community is far from resolved. Significant areas of research remain to be done. It is hoped that this report provides some degree of insight into the problems that require further study.

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Appendix A

Hush House Acoustic Model

A1. PRELIMINARY SOURCE MODEL

During the early stages of the AFGL research effort on Hush House vibro-acoustics a simple working hypothesis was developed to model the Hush House acoustic source. It was assumed that it could be modeled as a point source located over the exhaust stack and having the attributes of undeflected, plume generated, or jet, acoustics. The basis of this hypothesis was the direct visual observation of the turbulence over the exhaust deflector during Hush House operations at Luke AFB.

The spectral characteristics of plume generated acoustics can be represented in a theoretical form proposed by Powell.^{A1} This form holds for observations made in the far-field and for a flat earth location and is given by:

$$S_A(f, r_o) = \left(\frac{4 Q(r_o)}{\pi f_m} \right) \left(\left(\frac{f}{f_m} \right) + \left(\frac{f_m}{f} \right) \right)^{-2} \quad (A1)$$

where $S_A(f, r_o)$ is the acoustic emissions spectrum, $Q(r_o)$ is the Overall Sound Power Level (OASPL) of the source at a reference distance, r_o , f_m is the frequency of the spectral maximum of the source, and f is the frequency. On a logarithmic frequency axis, the form of the spectrum is a bell-shaped curve peaking at the

A1. Powell, A. (1964) Theory of vortex sound, J. Acoust. Soc. Am., 36:177-195.

frequency f_m . For fixed dimensions of the Hush House augmentor tube, the value of the OASPL and of f_m is controlled by the velocity of the air exiting the Hush House. In turn, the velocity of the exhaust should be related to the size and power setting of the engine being run in the Hush House.

During the analysis of the Luke data it became apparent that the Hush House acoustic source could not be represented by this simple model.⁵ The primary reasons that the model is unacceptable are the azimuthal dependency of the acoustic radiation pattern and a secondary maximum in the observed spectra that occurs below 10 Hz. Physical considerations and the appearance of pressure spectra for Hush House acoustic emissions indicate, however, that the source should still be related in some way to a jet.

A2. PRESENT WORKING HYPOTHESIS

It has been suggested that the secondary lobe in the Hush House emissions spectrum could be explained with a weak jet type source possibly associated with the air intake ducts.⁴ This combination of two point sources, one over the deflector and this secondary jet, would help to explain both the secondary spectral lobe and the non-uniform radiation pattern observed at Luke AFB. (An additional contribution to the non-symmetric radiation might also arise if the primary jet over the exhaust deflector is tilted rather than vertical. Thermographs of one Hush House exhaust plume do indicate a temperature distribution that is not vertical in the exhaust plume.¹¹)

As stated above, for a given Hush House design, the OASPL and the characteristic frequency f_m of each lobe are largely defined by the air velocity in the two jets. While the mass of air passing through the Hush House should essentially be conserved, the velocity at the air intakes is much lower, as the cross-sectional area of the intakes is greater and the average air temperature at the intakes is lower than the respective value at the exhaust. Therefore, the intake jet will be represented in the spectrum by a weaker lobe located at a lower frequency than the exhaust contribution. The hypothetical spectrum of the acoustic emissions can be constructed from the spectrum of each individual source and the resulting nominal form is shown in Figure A1.

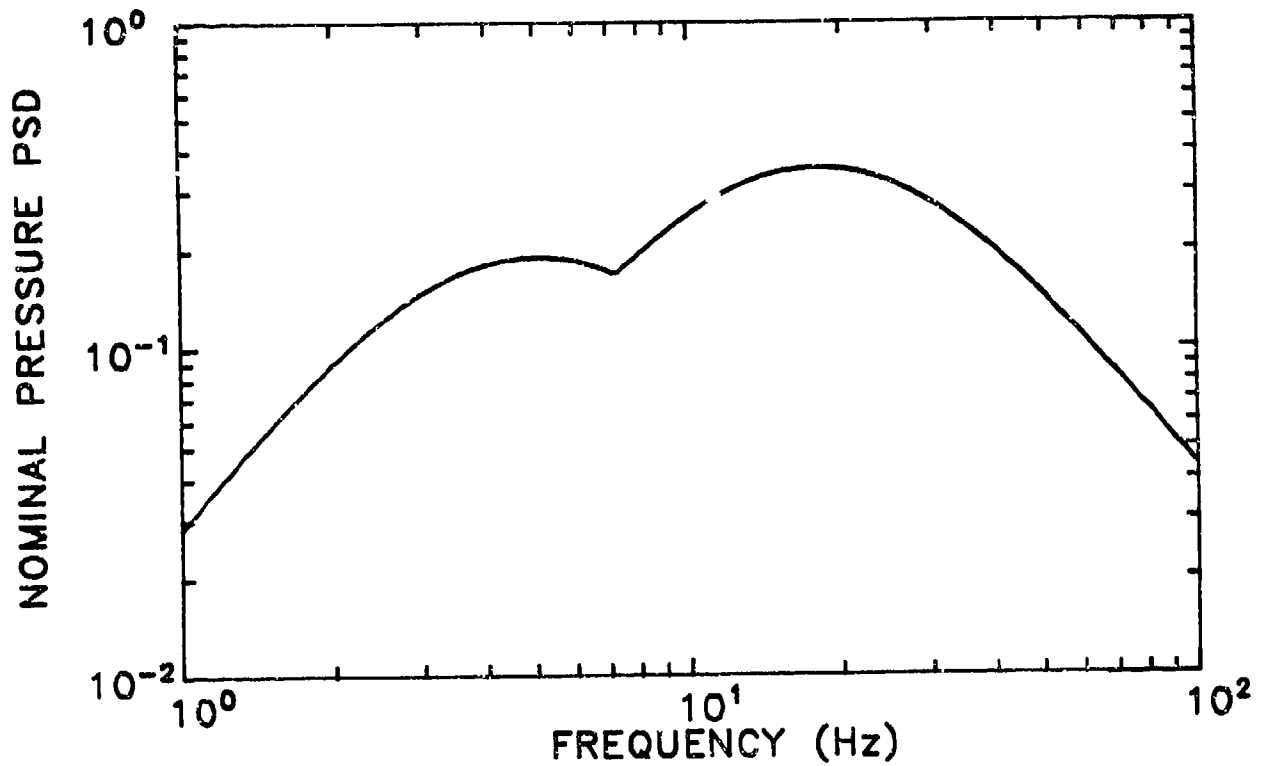


Figure A1. Theoretical Spectral Form of the Hush House Acoustic Emissions Based on the Working Hypothesis Model

Although this hypothesis has not been tested in any sense, the structure of the proposed Hush House source model can be seen in many of the observed pressure spectra from Fort Smith, Figures 6 through 13 of the main text, and in the data from Luke AFB. The secondary jet source is not always apparent in the Fort Smith data due to low signal-to-noise levels around 5 Hz.

Appendix B

Fort Smith Hush House Vibro-Acoustic Environment

B1. STATISTICS OF HUSH HOUSE VIBRO-ACOUSTICS

In this section, a short description of the Extreme Value Type I statistical distribution is given and the basis for the statistical approximations at site 4 are discussed. Along with these, the full statistics for each of the site measurements made at Fort Smith are presented. These statistics include values for idle and noise levels not referenced in the text. The noise statistics are based on data recorded essentially at random during the test period and might not be characteristic of the given site at any other time of day or season. It is unlikely that they represent either the extreme high or low noise conditions for the given site. They are presented only for general comparison with the motion environment during Hush House operations.

B2. EXTREME VALUE TYPE I DISTRIBUTION

The Extreme Value Type I distribution is an asymptotic distribution for the largest of n values of a random process as n becomes large.⁸ The assumptions in deriving the distribution are that the random process is unlimited in the positive direction and that the upper tail of the distribution governing the process falls off in an exponential manner. The normal distribution assumed above for the Hush House data satisfies these conditions.

The cumulative distribution function for the Extreme Value Type I distribution is given by:

$$F(y) = \exp[-\exp \{-a(y-u)\}] \quad (B1)$$

where a and u are parameters based on the mean and standard deviation of the sampled extreme values and $F(y)$ is the probability that the value will be less than or equal to y . In particular, the parameters are found to be given by:

$$u = 1.282/s \quad (B2)$$

and

$$a = 0.577/(m-u) \quad (B3)$$

where s is the sampled standard deviation and m is the sampled mean of the extreme values. Then, by inverting Eq. (A1), the level associated with a given probability of exceedence is found from the equation:

$$y = u - [\ln \{-\ln(F(y))\} / a] \quad (B4)$$

where $F(y)$ is the probability that y is less than or equal to Y . The probability of exceedence is then given by $[1 - F(y)]$.

B3. STATISTICAL APPROXIMATION FOR SITE 4

In general, the distribution parameters of the 1-sec window peak values are obtained directly from the recorded data. Due to the severe environment at site 4 the motions exceeded the dynamic range of the recording equipment. Given the parameters of the underlying full time series distribution it is possible, however, to estimate the parameters of the 1-sec window peak value and of the extreme value distribution.

To make this estimation requires a significant approximation. It will be recalled that the statistics for the windowed peak values were based on the absolute value of the peaks, in other words without regard to the sense of motion. The approximation that is used is based on the distribution of the signed peak value.

It can be argued heuristically that the means of the windowed data for the unsensed and sensed distribution should be essentially the same and that the variance of the sensed distribution should be slightly greater than that for the

unsensed distribution. Test comparisons were made using both the theoretical and direct sample estimation methods and agreement between the two methods was found to be very high.

It can be shown that, for an underlying process controlled by a zero mean normal distribution with a standard deviation given by s , the mean M of the n th value, x , from the top of a sample of m values is given by:

$$M = s \left\{ \sqrt{2 \ln m} - \left[\frac{\ln(\ln(m)) + \ln(4\pi) + 2(S_1 - C)}{2\sqrt{2 \ln m}} \right] \right\} \quad (B5)$$

and the standard deviation, D , is given by:

$$D = s \frac{\sqrt{\frac{\pi}{6} - S_2}}{\sqrt{2 \ln(m)}} \quad (B6)$$

where

$$S_1 = 1 + 1/2 + \cdots + 1/(n-1) \quad (B7)$$

and

$$S_2 = 1 + 1/4 + \cdots + 1/[(n-1)^2] \quad (B8)$$

and C denotes Euler's constant.^{B1} For the case of interest, the value of m is 100 and n is 1.

Given the estimated mean and standard deviations for the windowed data, then the extreme value distribution parameters can be determined from Eqs. (B2) and (B3).

B1. Cramer, H. (1958) Mathematical Methods of Statistics, Princeton University Press, Princeton, NJ.

B4. OBSERVED STATISTICS

Tables B1 through B3 provide the sampled statistical parameters for each site studied during the Fort Smith vibro-acoustic study as a function of aircraft and engine power setting. In addition, the statistics from a noise sample at each location are also included. Due to the limited duration of the study, insufficient noise data were taken at each site to fully characterize ambient conditions and the noise statistics should be viewed as just one sample taken from some unknown distribution.

Table B1 gives the statistics for the pressure sites, sites 5A through 5C and site 6. Table B2 gives the statistical parameters for the motion sensors in terms of velocity and Table B3 provides the analogous parameters for these sites in terms of displacement.

Table B1. Pressure Measurements for Operations in the Fort Smith Hush House

(Units of Pascals)

AIRCRAFT	POWER	SITE	FULL DISTRIBUTION		1.0 SEC PEAK DISTRIBUTION										MAXIMUM OBSERVED VALUE																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																						
			RMS	EXCEEDENCE LEVEL	EXCEEDENCE	MEAN	VARIANCE	STANDARD DEVIATION	EXCEEDENCE LEVEL	EXCEEDENCE	NORMAL	EXTREME																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																									
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NOTE: Measurements during idle were found to be essentially noise levels

Table B2a. Velocity Statistics for Operations in the Fort Smith Hush House; Site 1

(Units of Meters/Second)

AIRCRAFT	POWER	IDLE	RMS	FULL DISTRIBUTION		1.0 SEC PEAK DISTRIBUTION										MAXIMUM OBSERVED PEAK
				EXCEEDENCE LEVEL	0.001%	MEAN	VARIANCE	STANDARD DEVIATION	NORMAL		EXTREME VALUE TYPE I		EXCEEDENCE LEVEL	0.001%		
									LEVEL	U	ALPHA	U				
F-15	IDLE	R	1.805e-7	5.5775e-7	4.875e-7	8.629e-15	9.289e-8	7.7547e-7	1.381e7	4.456e-7	9.4576e-7	7.584e-7				
		T	2.03e-7	6.2727e-7	5.848e-7	8.131e-14	2.851e-7	1.4588e-6	4.498e6	4.565e-7	1.9921e-6	2.141e-6				
		V	1.951e-7	6.0286e-7	5.321e-7	6.789e-14	2.606e-7	1.3398e-6	4.922e5	4.148e-7	1.8181e-6	1.773e-6				
F-16	IDLE	R	3.135e-7	9.6872e-7	6.137e-7	1.093e-14	1.045e-7	1.1378e-6	1.227e7	7.666e-7	1.3295e-6	1.08e-6				
		T	4.002e-7	1.2366e-6	9.645e-7	6.343e-14	2.519e-7	1.7452e-6	5.092e6	8.511e-7	2.2076e-6	1.579e-6				
		V	2.57e-7	7.9413e-7	6.524e-7	1.578e-14	1.256e-7	1.0418e-6	1.021e7	5.958e-7	1.2723e-6	9.415e-7				
F-4	MP	R	7.226e-7	2.2328e-6	1.873e-6	1.314e-13	3.625e-7	2.9967e-6	3.538e6	1.71e-6	3.6623e-6	3.036e-6				
		T	5.566e-7	1.7261e-6	1.447e-6	6.769e-14	2.602e-7	2.2535e-6	4.93e6	1.33e-6	2.7311e-6	2.583e-6				
		V	9.976e-7	3.0826e-6	2.583e-6	2.702e-13	5.198e-7	4.1944e-6	2.467e6	2.349e-6	5.1489e-6	4.152e-6				
F-15	MP	R	9.623e-7	2.9735e-6	2.563e-6	1.911e-13	4.371e-7	3.9182e-6	2.934e6	2.366e-6	4.7202e-6	3.083e-6				
		T	7.773e-7	2.4019e-6	1.974e-6	1.033e-13	3.214e-7	2.9703e-6	3.991e6	1.829e-6	3.5597e-6	2.956e-6				
		V	1.327e-6	4.1004e-6	3.419e-6	3.053e-13	5.525e-7	5.1319e-6	2.321e6	3.17e-6	6.1460e-6	5.012e-6				
F-16	MP	R	8.563e-7	2.6460e-6	2.222e-6	1.268e-13	3.561e-7	3.3259e-6	3.602e6	2.062e-6	3.9796e-6	3.158e-6				
		T	6.531e-7	2.0181e-6	1.773e-6	9.166e-14	3.028e-7	2.7115e-6	4.236e6	1.637e-6	3.2676e-6	2.567e-6				
		V	1.239e-6	3.8285e-6	3.217e-6	4.33e-13	6.580e-7	5.2569e-6	1.949e6	2.291e-6	5.8350e-6	5.364e-6				
F-4	AB	R	1.429e-6	4.4156e-6	3.673e-6	3.996e-13	6.321e-7	5.6356e-6	2.029e6	3.389e-6	6.7933e-6	5.871e-6				
		T	1.225e-6	3.7853e-6	3.131e-6	2.621e-13	5.120e-7	4.7181e-6	2.505e6	2.9e-6	5.6574e-6	4.442e-6				
		V	2.188e-6	6.7609e-6	5.721e-6	1.055e-12	1.027e-6	8.9051e-6	1.249e5	5.259e-6	1.0789e-5	1.203e-5				
F-15	AB	R	2.402e-6	7.4222e-6	6.198e-6	9.296e-13	9.642e-7	9.1869e-6	1.33e6	5.764e-6	1.0957e-5	8.552e-6				
		T	1.951e-6	6.0286e-6	4.973e-6	8.303e-13	9.112e-7	7.7977e-6	1.408e6	4.563e-6	9.4687e-6	7.646e-6				
		V	3.769e-6	1.1646e-5	9.577e-6	2.611e-12	1.616e-6	1.4586e-5	7.938e5	8.85e-6	1.7552e-5	1.401e-5				
F-16	AB	R	1.80e-6	5.8052e-6	4.804e-6	7.534e-13	6.688e-7	7.5748e-6	1.478e6	4.493e-6	9.1664e-6	7.201e-6				
		T	1.581e-6	4.8653e-6	4.192e-6	4.635e-13	6.845e-7	6.3139e-6	1.874e6	3.884e-6	7.5698e-6	6.69e-6				
		V	3.0e-6	9.5821e-6	8.072e-6	2.633e-12	1.623e-6	1.3102e-5	7.903e5	7.342e-6	1.6082e-5	1.264e-5				
NOISE		R	9.616e-9	2.9712e-8	1.647e-8	1.669e-16	1.292e-8	5.6520e-8	9.925e7	1.065e-8	8.0235e-8	1.045e-7				
		T	9.278e-9	2.8668e-8	2.127e-8	4.060e-17	6.372e-9	4.1022e-8	2.013e8	1.940e-8	5.2717e-8	4.236e-8				
		V	9.221e-9	2.8494e-8	1.133e-8	1.8050e-8	1.343e-8	4.1660e-8	1.185e8	1.318e-8	7.1459e-8	6.606e-8				

Table B2b. Velocity Statistics for Operations in the Fort Smith Hush House; Site 2

(Units of Meters/Second)

Aircraft	Power	Chl	RMS	1.0 SEC PEAK DISTRIBUTION									
				FULL DISTRIBUTION		NORMAL		EXTREME VALUE TYPE I		0.001% EXCEEDENCE		0.001% EXCEEDENCE	
				LEVEL	EXCEEDENCE	MEAN	VARIANCE	STANDARD DEVIATION	LEVEL	EXCEEDENCE	ALPHA	U	LEVEL
F-15	IDLE	R	8.907e-7	2.7523e-6	1.849e-6	6.526e-13	8.078e-7	4.3533e-6	1.588e-6	1.486e-6	5.8357e-6	6.328e-6	
		T	1.058e-6	3.2692e-6	2.497e-6	4.33e-13	6.580e-7	4.5369e-6	1.949e-6	2.231e-6	5.7450e-6	5.326e-6	
		V	9.146e-8	2.5171e-7	2.297e-7	7.274e-15	8.529e-8	4.9409e-7	1.504e-7	1.913e-7	6.5056e-7	5.792e-7	
F-16	IDLE	R	2.152e-7	6.6497e-7	5.463e-7	1.225e-14	1.107e-7	8.8941e-7	1.159e-7	4.965e-7	1.2925e-6	8.97e-7	
		T	3.785e-7	1.1696e-6	6.475e-7	5.997e-14	2.449e-7	1.6067e-6	5.238e-6	7.373e-7	2.0560e-6	1.298e-6	
		V	1.415e-7	4.3724e-7	3.281e-7	8.828e-15	9.356e-8	5.1937e-7	1.365e-7	2.858e-7	7.5183e-7	5.065e-7	
F-4	MP	R	3.39e-7	7.3851e-7	6.721e-7	1.334e-14	1.155e-7	1.0301e-6	1.111e-7	6.201e-7	1.2418e-6	9.732e-7	
		T	3.254e-7	1.0055e-6	8.635e-7	1.81e-14	1.345e-7	1.2806e-6	9.532e-6	8.029e-7	1.5275e-6	1.256e-6	
		V	1.28e-7	3.9552e-7	3.449e-7	3.442e-15	5.867e-8	5.2677e-7	2.186e-7	3.185e-7	6.3448e-7	5.581e-7	
F-15	MP	R	1.534e-6	4.7401e-6	3.588e-6	1.637e-12	1.279e-6	7.5543e-6	1.003e-6	3.012e-6	9.8986e-6	1.137e-5	
		T	2.318e-6	7.1226e-6	5.359e-6	3.884e-12	1.971e-6	1.1468e-5	6.508e-5	4.473e-6	1.5086e-5	1.835e-5	
		V	1.83e-7	5.6547e-7	4.896e-7	4.389e-14	2.095e-7	1.1390e-6	6.122e-6	3.952e-7	1.5235e-6	2.125e-6	
F-16	MP	R	2.975e-7	9.1928e-7	8.316e-7	1.688e-14	1.299e-7	1.2344e-6	9.871e-6	7.731e-7	1.4729e-6	1.224e-6	
		T	4.206e-7	1.5997e-6	1.132e-6	4.229e-14	2.056e-7	1.7695e-6	6.237e-6	1.04e-6	2.1475e-6	2.232e-6	
		V	1.851e-7	5.7196e-7	4.958e-7	1.56e-14	1.249e-7	8.8299e-7	1.027e-7	4.396e-7	1.1122e-6	1.113e-6	
F-4	AB	R	4.781e-7	1.4773e-6	1.327e-6	4.555e-14	2.134e-7	1.9886e-6	6.009e-6	1.231e-6	2.3805e-6	1.911e-6	
		T	6.665e-7	2.0595e-6	1.774e-6	8.729e-14	2.954e-7	2.6899e-6	4.341e-6	1.641e-6	3.2322e-6	2.602e-6	
		V	2.579e-7	7.9631e-7	6.933e-7	5.838e-14	2.416e-7	1.4423e-6	5.308e-6	5.846e-7	1.8859e-6	2.732e-6	
F-15	AB	R	4.447e-6	1.3741e-5	1.053e-5	6.763e-12	2.601e-6	1.8592e-5	4.932e-5	9.357e-6	2.3362e-5	1.945e-5	
		T	7.642e-6	2.3614e-5	1.71e-5	1.998e-11	4.470e-6	3.0957e-5	2.87e-5	1.509e-5	3.9157e-5	3.076e-5	
		V	3.806e-7	1.1751e-6	1.049e-6	3.033e-14	1.742e-7	1.5889e-6	7.364e-6	9.709e-7	1.9089e-6	1.626e-6	
F-16	AB	R	7.014e-7	2.1673e-6	1.876e-6	8.497e-14	2.915e-7	2.7796e-6	4.4e-6	1.745e-6	3.3148e-6	2.952e-6	
		T	8.652e-7	2.6858e-6	2.311e-6	1.077e-13	3.282e-7	3.3263e-6	3.908e-6	2.164e-6	3.9315e-6	3.184e-6	
		V	2.732e-7	1.1532e-6	1.016e-6	2.477e-14	1.574e-7	1.5039e-6	8.149e-6	9.448e-7	1.7924e-6	1.403e-6	
NOISE		R	1.824e-7	5.6532e-7	4.576e-7	1.461e-14	1.209e-7	8.3234e-7	1.061e-7	4.032e-7	1.0542e-6	1.033e-6	
		T	1.852e-7	5.7484e-7	4.832e-7	1.533e-14	1.239e-7	8.6732e-7	1.035e-7	4.274e-7	1.0948e-6	1.148e-6	
		V	9.384e-8	2.9892e-7	2.484e-7	5.665e-15	7.527e-8	4.8174e-7	1.704e-7	2.145e-7	6.1985e-7	6.129e-7	

Table B2c. Velocity Statistics for Operations in the Fort Smith Hush House; Site 3

(Units of Meters/Second)

AIRCRAFT	POWER	CHL	RMS	FULL DISTRIBUTION		1.0 SEC PEAK DISTRIBUTION										MAXIMUM OBSERVED PEAK
				EXCEEDENCE LEVEL	0.001%	MEAN	VARIANCE	STANDARD DEVIATION	NORMAL		EXTREME VALUE TYPE I					
									EXCEEDENCE LEVEL	0.001%	ALPHA	U	EXCEEDENCE LEVEL	0.001%		
F-4	IDLE	R	4.438e-7	1.3713e-6	1.074e-6	4.609e-13	6.789e-7	3.1786e-6	1.889e-6	7.686e-7	4.4252e-6	3.857e-6				
		T	4.088e-7	1.2632e-6	1.034e-7	2.341e-13	4.838e-7	1.6033e-6	2.651e-6	8.16e-7	3.4215e-6	3.146e-6				
		V	3.802e-8	3.0288e-7	2.658e-7	2.177e-14	1.475e-7	7.2319e-7	8.692e-6	1.994e-7	9.9407e-7	7.388e-7				
F-4	MIL	R	3.663e-6	1.1319e-5	9.656e-6	3.187e-12	1.785e-6	1.5190e-5	7.185e-5	8.853e-6	1.8466e-5	1.596e-5				
		T	2.286e-6	7.0637e-6	5.895e-6	1.268e-12	1.128e-6	9.3758e-6	1.139e-5	5.378e-6	1.1442e-5	1.19e-5				
		V	6.39e-7	1.9745e-6	1.723e-6	7.921e-14	2.814e-7	2.5955e-6	4.577e-6	1.596e-6	3.1051e-6	2.884e-6				
F-15	MIL	R	5.673e-6	1.7530e-5	1.531e-5	5.663e-12	2.380e-6	2.2687e-5	3.389e-5	1.423e-5	2.7047e-5	2.358e-5				
		T	3.593e-6	1.1102e-5	9.026e-6	2.122e-12	1.457e-6	1.3542e-5	8.805e-5	8.37e-6	1.6215e-5	1.27e-5				
		V	1.04e-6	3.2136e-6	2.758e-6	1.831e-13	4.279e-7	4.1245e-6	2.997e-6	2.606e-6	4.9107e-6	4.18e-6				
F-16	MIL	R	6.209e-6	2.1349e-5	1.779e-5	1.224e-11	3.499e-6	2.8636e-5	3.665e-5	1.621e-5	3.5057e-5	2.958e-5				
		T	4.195e-6	1.2963e-5	1.065e-5	4.579e-12	2.140e-6	1.7284e-5	5.995e-5	9.688e-6	2.1210e-5	1.928e-5				
		V	1.028e-6	3.1765e-6	2.765e-6	2.212e-13	4.703e-7	7.2230e-6	2.737e-6	2.553e-6	5.0767e-6	4.919e-6				
F-4	AB	R	1.019e-5	3.1487e-5	2.560e-5	2.248e-11	4.741e-6	4.0296e-5	2.705e-5	2.384e-5	4.9375e-5	4.116e-5				
		T	6.214e-6	1.9201e-5	1.568e-5	8.445e-12	2.906e-6	2.4689e-5	4.413e-5	1.437e-5	3.0022e-5	2.352e-5				
		V	1.558e-6	4.8451e-6	4.116e-6	5.274e-13	7.262e-7	6.3673e-6	1.766e-6	3.789e-6	7.7002e-6	6.511e-6				
F-15	AB	R	2.052e-5	6.3716e-5	5.381e-5	1.223e-10	1.105e-5	8.8093e-5	1.16e-5	4.884e-5	1.0839e-4	8.867e-5				
		T	1.113e-5	3.4392e-5	2.805e-5	4.157e-11	6.447e-6	4.8037e-5	1.989e-5	2.515e-5	5.9877e-5	4.617e-5				
		V	2.923e-6	9.0321e-6	7.806e-6	1.029e-12	1.014e-6	1.0951e-5	1.264e-6	7.35e-6	1.2815e-5	9.924e-6				
F-16	AB	R	2.323e-5	7.1761e-5	5.865e-5	9.247e-11	9.616e-6	8.8460e-5	1.334e-5	5.432e-5	1.0610e-4	8.277e-5				
		T	1.259e-5	3.8903e-5	3.17e-5	4.387e-11	6.623e-6	5.2233e-5	1.936e-5	2.871e-5	6.4388e-5	5.142e-5				
		V	3.198e-6	9.8819e-6	8.346e-6	2.4e-12	1.549e-6	1.3148e-5	8.279e-5	7.649e-6	1.5992e-5	1.297e-5				
NOISE		R	7.413e-7	2.2907e-6	1.856e-6	3.611e-14	1.903e-7	2.4449e-6	6.750e-6	1.770e-6	2.7937e-6	2.769e-6				
		T	6.640e-7	2.0518e-6	1.457e-6	4.869e-14	2.207e-7	2.1415e-6	5.812e-6	1.358e-6	2.5465e-6	2.166e-6				
		V	2.235e-7	9.9958e-7	5.669e-7	2.242e-15	4.735e-8	7.1368e-7	2.709e-7	5.456e-7	8.0059e-7	7.255e-7				
NOISE		R	3.641e-9	1.1249e-8	8.659e-9	2.262e-18	1.504e-9	1.3321e-8	8.528e-8	7.982e-9	1.6082e-8	1.420e-8				
		T	2.884e-9	8.9114e-9	7.428e-9	2.475e-18	1.573e-9	1.2305e-8	8.153e-8	6.720e-9	1.5193e-8	1.603e-8				
		V	2.278e-9	7.0395e-9	5.410e-9	2.060e-18	1.435e-9	9.8595e-9	8.936e-8	4.764e-9	1.2494e-8	9.656e-9				

Table B2d. Velocity Statistics for Operations in the Fort Smith Hush House; Site 4

(Units of Meters/Second)

AIRCRAFT	POWER	CHL	RMS	1.0 SEC PEAK DISTRIBUTION										MAXIMUM OBSERVED PEAK
				FULL DISTRIBUTION		EXTREME VALUE TYPE I								
				EXCEEDENCE LEVEL	0.001%	MEAN	VARIANCE DEVIATION	STANDARD DEVIATION	EXCEEDENCE LEVEL	0.001%	ALPHA	U	EXCEEDENCE LEVEL	
F-4	IDLE	R	5.358e-5	1.6556e-4	1.348e-4	6.094e-10	2.469e-5	2.1133e-4	5.195e-4	1.237e-4	2.5666e-4	2.137e-4		
		T	3.44e-5	1.0630e-4	9.03e-5	1.997e-10	1.413e-5	1.3411e-4	9.075e-4	8.394e-5	1.6005e-4	1.288e-4		
		V	1.344e-5	4.1530e-5	3.249e-5	6.285e-11	7.928e-6	5.7066e-5	1.618e-5	2.892e-5	7.1610e-5	6.218e-5		
F-4	MIL	R	6.98e-4	2.1506e-3	1.663e-3	1.574e-8	1.255e-4	2.0519e-3	1.022e-3	1.606e-3	2.2819e-3	1.931e-3		
		T	3.791e-4	1.1714e-3	9.279e-4	1.266e-8	1.125e-4	1.2767e-3	1.14e-3	8.773e-4	1.4832e-3	1.188e-3		
		V	1.441e-4	4.4527e-4	3.638e-4	3.178e-9	5.637e-5	5.3856e-4	2.275e-4	3.384e-4	6.4202e-4	5.096e-4		
F-15	MIL	R*	8.8e-4	2.7192e-3	2.345e-3	1.3831e-7	3.719e-4	3.4973e-3	3.449e-3	2.177e-3	4.1800e-3	CLIPPED		
		T	4.382e-4	1.3540e-3	1.059e-3	2.449e-8	1.555e-4	1.5441e-3	8.195e-3	9.888e-4	1.8317e-3	1.406e-3		
		V	1.348e-4	4.1653e-4	3.533e-4	3.416e-9	5.845e-5	5.3448e-4	2.194e-4	3.27e-4	6.4182e-4	4.916e-4		
F-16	MIL	R*	9e-4	2.781e-3	2.395e-3	1.4434e-7	3.799e-4	3.5729e-3	3.376e-3	2.224e-3	4.2702e-3	CLIPPED		
		T	5.368e-4	1.6587e-3	1.23e-3	2.536e-8	1.592e-4	1.7837e-3	8.054e-3	1.219e-3	2.0766e-3	1.585e-3		
		V	2.051e-4	6.3376e-4	5.353e-4	8.521e-9	9.285e-5	8.2313e-4	1.381e-4	4.935e-4	9.9366e-4	8.62e-4		
F-4	AB	R*	1.1e-3	3.399e-3	2.921e-3	2.1610e-7	4.649e-4	4.3717e-3	2.759e-3	2.721e-3	5.2250e-3	CLIPPED		
		T	6.91e-4	2.1352e-3	1.461e-3	9.192e-8	9.587e-5	1.7582e-3	1.338e-3	1.417e-3	1.9332e-3	1.651e-3		
		V	3.182e-4	9.8324e-4	8.466e-4	2.157e-8	1.465e-4	1.3019e-3	8.734e-3	7.805e-4	1.5713e-3	1.385e-3		
F-15	AB	R*	2.9e-3	8.951e-3	7.726e-3	1.5020e-6	1.226e-3	1.1525e-2	1.047e-3	7.175e-3	1.3775e-2	CLIPPED		
		T*	1.7e-3	5.253e-3	4.529e-3	5.1614e-7	7.184e-4	6.7562e-3	1.785e-3	4.206e-3	8.0749e-3	CLIPPED		
		V*	6.8e-4	2.1012e-3	1.812e-3	8.2503e-8	2.874e-4	2.7025e-3	4.463e-3	1.682e-3	3.2300e-3	CLIPPED		
F-16	AB	R*	2.9e-3	8.951e-3	1.455e-3	1.5020e-6	1.226e-3	1.8349e-2	1.047e-3	1.400e-2	2.0599e-2	CLIPPED		
		T*	1.7e-3	5.253e-3	8.529e-3	5.1614e-7	7.184e-4	1.0756e-2	1.785e-3	8.206e-3	1.2075e-2	CLIPPED		
		V*	7.1e-4	2.1939e-3	1.892e-3	9.0030e-8	3.001e-4	2.8217e-3	4.274e-3	1.757e-3	3.3725e-3	CLIPPED		
NOISE		R	1.583e-5	4.8899e-5	4.208e-5	4.041e-11	6.357e-6	6.1785e-5	2.018e-5	3.922e-5	7.3453e-5	5.619e-5		
		T	1.415e-5	4.3740e-5	3.432e-5	5.177e-11	7.195e-6	5.6628e-5	1.783e-5	3.109e-5	6.9834e-5	5.607e-5		
		V	3.068e-6	9.4809e-6	7.971e-6	1.487e-12	1.220e-6	1.1752e-5	1.052e-6	7.422e-6	1.3991e-5	1.031e-5		

NOTE: Components marked with a star had clipped data and approximate statistical functions were used to estimate values.

Table B2e. Velocity Statistics for Operations in the Fort Smith Hush House; Sites 7 and 8

(Units of Meters/Second)

AIRCRAFT	POWER	ICHL	RMS	1.0 SEC PEAK DISTRIBUTION										EXTREME VALUE TYPE I		MAXIMUM OBSERVED
				FULL DISTRIBUTION		MEAN	VARIANCE	STANDARD DEVIATION	EXCEEDENCE	NORMAL		ALPHA	U	EXCEEDENCE	LEVEL	
				EXCEEDENCE	LEVEL					0.001%	0.001%					
F-4	MP	R	3.457e-7	1.0713e-6	8.827e-7	5.233e-14	2.288e-7	1.5919e-6	5.607e6	7.798e-7	2.0117e-6	1.452e-6				
		T	4.597e-7	1.4203e-6	1.194e-6	1.615e-13	4.019e-7	2.4402e-6	3.192e6	1.014e-6	3.1778e-6	2.527e-6				
		V	1.989e-7	6.1459e-7	5.293e-7	1.052e-14	1.022e-7	8.4715e-7	1.251e7	4.822e-7	1.0345e-6	8.746e-7				
F-15	MP	R	4.356e-7	1.3461e-6	1.133e-6	5.209e-14	2.282e-7	1.8409e-6	5.619e6	1.031e-6	2.2599e-6	1.879e-6				
		T	5.132e-7	1.5858e-6	1.338e-6	1.885e-13	4.342e-7	2.6838e-6	2.954e6	1.143e-6	3.4807e-6	3.242e-6				
		V	2.437e-7	7.5311e-7	6.502e-7	1.377e-14	1.172e-7	1.0140e-6	1.093e7	5.974e-7	1.2294e-6	1.002e-6				
F-16	MP	R	4.436e-7	1.3706e-6	1.188e-6	8.527e-14	2.920e-7	2.0930e-6	4.392e6	1.056e-6	2.6290e-6	2.118e-6				
		T	7.715e-7	2.3839e-6	2.080e-6	9.933e-13	9.967e-7	5.1701e-6	1.287e6	1.632e-6	6.9995e-6	4.747e-6				
		V	2.622e-7	8.1005e-7	7.111e-7	2.010e-14	1.418e-7	1.1506e-6	2.046e6	6.473e-7	1.4108e-6	1.202e-6				
F-4	AB	R	7.169e-7	2.2151e-6	1.781e-6	1.264e-13	3.583e-7	2.8920e-6	3.580e6	1.620e-6	3.5497e-6	2.868e-6				
		T	7.073e-7	2.1855e-6	1.829e-6	2.353e-13	4.851e-7	3.333e-6	2.544e6	1.611e-6	4.2237e-6	4.189e-6				
		V	5.042e-7	1.5580e-6	1.344e-6	4.363e-14	2.089e-7	1.9911e-6	6.140e6	1.250e-6	2.3745e-6	2.025e-6				
F-15	AB	R	1.365e-6	4.2186e-6	3.304e-6	2.777e-13	5.270e-7	4.9381e-6	2.434e6	3.067e-6	5.9035e-6	4.974e-6				
		T	1.004e-6	3.1037e-6	2.557e-6	2.667e-13	5.164e-7	4.1583e-6	2.484e6	2.325e-6	5.1062e-6	3.645e-6				
		V	7.578e-7	2.3416e-6	2.072e-6	1.169e-13	3.420e-7	3.1320e-6	3.750e6	1.918e-6	3.7597e-6	3.120e-6				
F-16	AB	R	1.080e-6	3.3371e-6	2.674e-6	2.944e-13	5.426e-7	4.3563e-6	2.364e6	2.430e-6	5.3523e-6	4.245e-6				
		T	9.781e-7	3.0225e-6	2.381e-6	1.392e-12	1.179e-6	6.0366e-6	1.088e6	1.851e-6	8.2009e-6	8.972e-6				
		V	7.553e-7	2.3338e-6	1.986e-6	1.369e-13	3.700e-7	3.1334e-6	3.466e6	1.820e-6	3.8126e-6	3.503e-6				
NOISE (Site 7)		R	1.911e-7	5.9041e-7	5.017e-7	1.941e-14	1.393e-7	9.335e-7	9.206e6	4.390e-7	1.1894e-6	9.339e-7				
		T	3.354e-7	1.0365e-6	8.680e-7	1.111e-13	3.33e-7	1.9013e-6	3.848e6	7.179e-7	2.5132e-6	1.819e-6				
		V	9.700e-8	2.9971e-7	9.700e-8	4.956e-15	7.040e-8	3.1523e-7	1.022e7	2.272e-7	6.0632e-7	5.406e-7				
NOISE (Site 8)		R	4.893e-7	1.5119e-6	1.147e-6	3.720e-13	6.099e-7	3.0377e-6	2.103e6	8.726e-7	4.1572e-6	4.578e-6				
		T	8.579e-7	2.6510e-6	2.081e-6	8.058e-13	8.992e-7	4.8695e-6	1.426e6	1.676e-6	6.5190e-6	5.228e-6				
		V	2.052e-7	6.3393e-7	5.250e-7	5.768e-14	2.402e-7	1.2695e-6	5.340e6	4.169e-7	1.7103e-6	1.892e-6				

Table B3a. Displacement Statistics for Operations in the Fort Smith Hush House; Site 1

(Units of Meters)

AIRCRAFT	POWER	CHL	FULL DISTRIBUTION			1.0 SEC PEAK DISTRIBUTION										MAXIMUM OBSERVED
			RMS	EXCEEDENCE LEVEL	0.001% EXCEEDENCE	MEAN	VARIANCE	STANDARD DEVIATION	0.001% EXCEEDENCE LEVEL	EXTREME VALUE TYPE I			0.001% EXCEEDENCE LEVEL			
										ALPHA	U					
F-15	IDLE	R	6.258e-9	1.3337e-8	1.326e-8	1.326e-8	2.405e-17	4.904e-9	2.8463e-8	2.615e8	1.105e-8	1.105e-8	3.7464e-8	3.677e-8		
		T	8.076e-9	2.4955e-8	1.46e-8	1.46e-8	8.131e-17	9.017e-9	4.2553e-8	1.422e8	1.054e-8	1.054e-8	5.9114e-8	5.482e-8		
		V	7.971e-9	2.4630e-8	1.572e-8	1.572e-8	8.247e-17	9.081e-9	4.3872e-8	1.412e8	1.154e-8	1.154e-8	6.0558e-8	5.502e-8		
F-16	IDLE	R	6.404e-9	1.9788e-8	1.549e-8	1.549e-8	5.291e-18	2.300e-9	2.2621e-8	5.576e8	1.445e-8	1.445e-8	2.6837e-8	2.151e-8		
		T	5.087e-9	1.5719e-8	1.313e-8	1.313e-8	8.111e-18	2.848e-9	2.1959e-8	4.503e8	1.185e-8	1.185e-8	2.7189e-8	2.035e-8		
		V	6.333e-9	1.9569e-8	1.452e-8	1.452e-8	1.339e-17	3.659e-9	2.5864e-8	3.506e8	1.287e-8	1.287e-8	3.2571e-8	2.869e-8		
F-4	MIL	R	1.002e-8	3.3434e-8	2.779e-8	2.779e-8	4.034e-17	6.398e-9	4.7615e-8	2.005e8	2.49e-8	2.49e-8	5.9350e-8	4.515e-8		
		T	1.024e-8	3.1642e-8	2.342e-8	2.342e-8	1.269e-16	1.126e-8	5.8341e-8	1.139e8	1.835e-8	1.835e-8	7.8993e-8	9.359e-8		
		V	1.837e-8	5.6763e-8	4.433e-8	4.433e-8	2.086e-16	1.444e-8	8.9103e-8	8.881e7	3.783e-8	3.783e-8	1.1561e-7	1.169e-7		
F-15	MIL	R	1.527e-8	4.7184e-8	3.878e-8	3.878e-8	5.382e-17	7.336e-9	6.1522e-8	1.748e8	3.547e-8	3.547e-8	7.4985e-8	6.303e-8		
		T	1.385e-8	4.2797e-8	3.039e-8	3.039e-8	1.328e-16	1.152e-8	6.6114e-8	1.113e8	2.52e-8	2.52e-8	8.7260e-8	8.485e-8		
		V	2.31e-8	7.1379e-8	5.66e-8	5.66e-8	1.971e-16	1.404e-8	1.0018e-7	9.136e7	5.034e-8	5.034e-8	1.2594e-7	1.188e-7		
F-16	MIL	R	1.169e-8	3.6122e-8	3.042e-8	3.042e-8	2.427e-17	4.926e-9	4.5692e-8	2.603e8	2.82e-8	2.82e-8	5.4736e-8	4.596e-8		
		T	7.67e-9	2.3700e-8	2.069e-8	2.069e-8	1.551e-17	3.938e-9	3.2899e-8	3.257e8	1.892e-8	1.892e-8	4.0127e-8	3.125e-8		
		V	1.541e-8	5.9977e-8	4.932e-8	4.932e-8	1.017e-16	1.008e-8	8.0582e-8	1.271e8	4.478e-8	4.478e-8	9.9125e-8	7.264e-8		
F-4	AB	R	1.875e-8	5.7938e-8	892e-8	892e-8	7.378e-17	8.590e-9	7.5548e-8	1.493e8	4.506e-8	4.506e-8	9.1324e-8	8.582e-8		
		T	1.405e-8	4.3415e-8	1.62e-8	1.62e-8	5.209e-17	7.217e-9	5.6994e-8	1.777e8	3.137e-8	3.137e-8	7.0240e-8	5.473e-8		
		V	3.232e-8	9.9869e-8	8.004e-8	8.004e-8	2.163e-16	1.471e-8	1.2563e-7	8.721e7	7.342e-8	7.342e-8	1.5263e-7	1.141e-7		
F-15	AB	R	3.428e-8	1.0531e-7	8.593e-8	8.593e-8	2.283e-16	1.511e-8	1.3277e-7	8.489e7	7.913e-8	7.913e-8	1.6050e-7	1.241e-7		
		T	2.257e-8	6.9741e-8	5.733e-8	5.733e-8	1.586e-16	1.259e-8	9.6370e-8	1.018e8	5.167e-8	5.167e-8	1.1952e-7	1.092e-7		
		V	6.296e-8	1.9455e-7	1.437e-7	1.437e-7	1.387e-15	3.724e-8	2.5885e-7	3.443e7	1.267e-7	1.267e-7	3.2732e-7	2.453e-7		
F-16	AB	R	3.357e-8	7.2831e-8	6.186e-8	6.186e-8	1.342e-16	1.158e-8	9.7772e-8	1.107e8	5.665e-8	5.665e-8	1.1905e-7	9.621e-8		
		T	1.547e-8	4.7802e-8	4.171e-8	4.171e-8	3.792e-17	6.158e-9	6.0800e-8	2.083e8	3.893e-8	3.893e-8	7.2090e-8	6.492e-8		
		V	4.693e-8	1.4501e-7	1.133e-7	1.133e-7	5.943e-16	2.438e-8	1.8887e-7	5.262e7	1.023e-7	1.023e-7	2.3357e-7	1.936e-7		
NOISE		R	2.9712e-8	1.647e-8	1.647e-8	1.647e-8	1.663e-16	1.292e-8	5.6520e-8	9.926e7	1.055e-8	1.055e-8	8.0236e-8	1.045e-7		
		T	2.8668e-8	2.127e-8	2.127e-8	2.127e-8	4.03e-17	6.37e-9	4.1022e-8	2.013e8	1.842e-8	1.842e-8	5.2717e-8	4.236e-8		
		V	2.8494e-8	1.133e-7	1.133e-7	1.133e-7	1.550e-16	1.343e-8	4.1660e-8	1.185e8	1.316e-8	1.316e-8	7.145e-8	6.606e-8		

Table B3b. Displacement Statistics for Operations in the Fort Smith Hush House; Site 2

(Units of Meters)

AIRCRAFT	POWER	ICHL	RMS	FULL DISTRIBUTION		1.6 SEC PEAK DISTRIBUTION										MAXIMUM OBSERVED PEAK	
				EXCEEDENCE LEVEL	MEAN	VARIANCE	STANDARD DEVIATION	NORMAL		EXTREME VALUE	TYPE I	EXCEEDENCE LEVEL		U			
								0.001%	0.001%			0.001%	0.001%				
F-15	IDLE	R	9.048e-9	2.7958e-8	1.979e-8	3.553e-17	5.961e-9	3.8268e-8	2.624e8	1.71e-8	4.3423e-8	1.71e-8	4.3423e-8	1.71e-8	4.3423e-8	4.099e-8	
		T	7.635e-9	2.3592e-8	1.922e-8	2.389e-17	4.888e-9	3.4372e-8	2.624e8	1.702e-8	4.3343e-8	1.702e-8	4.3343e-8	1.702e-8	4.3343e-8	3.645e-8	
		V	2.749e-9	8.4944e-9	6.021e-9	2.665e-18	1.632e-9	1.1082e-8	7.856e8	5.286e-9	1.4078e-8	5.286e-9	1.4078e-8	5.286e-9	1.4078e-8	1.032e-8	
F-16	IDLE	R	3.081e-9	9.5203e-9	7.633e-9	1.279e-18	1.131e-9	1.1139e-8	1.134e9	7.124e-9	1.3215e-8	1.134e9	7.124e-9	1.3215e-8	1.134e9	1.225e-8	
		T	3.391e-9	1.0478e-8	6.647e-9	2.553e-18	1.598e-9	1.3500e-8	8.027e9	7.928e-9	8.7885e-9	8.027e9	7.928e-9	8.7885e-9	8.027e9	1.412e-8	
		V	1.952e-9	6.0317e-9	4.801e-9	8.481e-19	9.21e-10	7.6599e-9	1.393e9	4.386e-9	9.3445e-9	1.393e9	4.386e-9	9.3445e-9	1.393e9	9.018e-9	
F-4	MP	R	3.846e-9	1.1884e-8	9.813e-9	3.559e-18	1.887e-9	1.5661e-8	6.798e8	8.964e-9	1.9125e-8	6.798e8	8.964e-9	1.9125e-8	6.798e8	1.462e-8	
		T	4.042e-9	1.2490e-8	1.051e-8	4.031e-18	2.008e-9	1.6834e-8	6.388e8	9.709e-9	2.0522e-8	6.388e8	9.709e-9	2.0522e-8	6.388e8	1.569e-8	
		V	3.28e-9	1.0135e-8	7.21e-9	5.447e-18	2.334e-9	1.4445e-8	5.495e8	6.159e-9	1.8729e-8	5.495e8	6.159e-9	1.8729e-8	5.495e8	1.549e-8	
F-15	MP	R	1.398e-8	4.3198e-8	3.429e-8	9.634e-17	9.815e-9	6.4717e-8	1.307e8	2.987e-8	8.2718e-8	1.307e8	2.987e-8	8.2718e-8	1.307e8	9.173e-8	
		T	1.775e-8	5.4848e-8	4.455e-8	1.593e-16	1.262e-8	6.3686e-8	1.016e8	3.888e-8	1.0686e-7	1.016e8	3.888e-8	1.0686e-7	1.016e8	1.185e-7	
		V	8.395e-9	2.5941e-8	1.558e-8	3.092e-17	5.561e-9	3.2818e-8	2.307e8	1.308e-8	4.3020e-8	2.307e8	1.308e-8	4.3020e-8	2.307e8	2.934e-8	
F-16	MP	R	4.233e-9	1.3080e-8	1.092e-8	5.811e-18	2.411e-9	1.8393e-8	5.321e6	9.034e-9	2.2819e-8	5.321e6	9.034e-9	2.2819e-8	5.321e6	1.952e-8	
		T	4.655e-9	1.4369e-8	1.252e-8	4.744e-18	2.178e-9	1.9272e-8	5.889e8	1.154e-8	2.3269e-8	5.889e8	1.154e-8	2.3269e-8	5.889e8	2.197e-8	
		V	2.962e-9	9.1526e-9	7.135e-9	6.696e-18	2.588e-9	1.5157e-8	4.956e8	5.97e-9	1.9907e-8	4.956e8	5.97e-9	1.9907e-8	4.956e8	2.157e-8	
F-4	AB	R	5.717e-9	1.7665e-8	1.528e-8	6.872e-18	2.623e-9	2.3410e-8	4.89e8	1.41e-8	2.8225e-8	4.89e8	1.41e-8	2.8225e-8	4.89e8	2.307e-8	
		T	7.453e-9	2.3048e-8	1.932e-8	1.176e-17	3.429e-9	2.9951e-8	3.739e8	1.778e-8	3.6254e-8	3.739e8	1.778e-8	3.6254e-8	3.739e8	2.989e-8	
		V	4.033e-9	1.2462e-8	9.993e-9	7.048e-18	2.655e-9	1.8223e-8	4.831e8	8.798e-9	2.3096e-8	4.831e8	8.798e-9	2.3096e-8	4.831e8	2.139e-8	
F-15	AB	R	3.053e-8	9.4338e-8	7.721e-8	2.268e-16	1.506e-8	1.2390e-7	8.517e7	7.043e-8	1.5153e-7	8.517e7	7.043e-8	1.5153e-7	8.517e7	1.207e-7	
		T	5.611e-8	1.7338e-7	1.326e-7	7.743e-16	2.783e-8	2.1886e-7	4.609e7	1.201e-7	2.6996e-7	4.609e7	1.201e-7	2.6996e-7	4.609e7	2.14e-7	
		V	8.764e-9	2.7081e-8	1.863e-8	2.52e-17	5.020e-9	3.4392e-8	2.555e8	1.657e-8	4.3604e-8	2.555e8	1.657e-8	4.3604e-8	2.555e8	3.743e-8	
F-16	AB	R	6.853e-9	2.1207e-8	1.883e-8	8.558e-18	2.925e-9	2.7899e-8	4.384e8	1.751e-8	3.3266e-8	4.384e8	1.751e-8	3.3266e-8	4.384e8	2.667e-8	
		T	8.778e-9	2.7130e-8	2.318e-8	1.758e-17	4.193e-9	3.6178e-8	3.059e8	2.129e-8	4.3870e-8	3.059e8	2.129e-8	4.3870e-8	3.059e8	3.726e-8	
		V	4.555e-9	1.4075e-8	1.201e-8	4.273e-18	2.067e-9	1.8418e-8	6.098e8	1.106e-8	2.2391e-8	6.098e8	1.106e-8	2.2391e-8	6.098e8	1.979e-8	
NOISE		R	3.641e-9	1.1249e-8	8.659e-9	2.262e-18	1.504e-9	1.3321e-8	8.528e8	7.982e-9	1.6082e-8	8.528e8	7.982e-9	1.6082e-8	8.528e8	1.420e-8	
		T	2.804e-9	8.9114e-9	7.428e-9	2.475e-18	1.573e-9	1.2305e-8	8.153e8	6.720e-9	1.5193e-8	8.153e8	6.720e-9	1.5193e-8	8.153e8	1.603e-8	
		V	2.278e-9	7.0395e-9	5.410e-9	2.060e-18	1.435e-9	9.8595e-9	8.936e8	4.764e-9	1.2494e-8	8.936e8	4.764e-9	1.2494e-8	8.936e8	9.656e-9	

Table B3c. Displacement Statistics for Operations in the Fort Smith Hush House; Site 3

(Units of Meters)

AIRCRAFT	POWER	CHL	FULL DISTRIBUTION		1.0 SEC PEAK DISTRIBUTION										MAXIMUM OBSERVED PEAK
			RMS	EXCEEDENCE LEVEL	MEAN	VARIANCE	STANDARD DEVIATION	NORMAL		EXTREME VALUE		TYPE I	EXCEEDENCE LEVEL	U	
								0.001% EXCEEDENCE	0.001% LEVEL	0.001% EXCEEDENCE	0.001% LEVEL				
F-4	IDLE	R	5.03e-9	1.5543e-8	8.15e-9	1.344e-17	3.666e-9	1.9555e-8	3.499e-8	6.54e-9	2.6281e-8	3.32e-8			
		T	5.051e-9	1.5608e-8	8.256e-9	1.244e-17	3.527e-9	1.9190e-8	3.636e-8	6.668e-9	2.5665e-8	3.125e-8			
		V	2.187e-9	6.7578e-9	2.998e-9	2.675e-18	1.636e-9	8.0682e-9	7.842e-8	2.262e-9	1.1070e-8	1.744e-8			
F-4	MIL	R	4.101e-8	1.2672e-7	1.057e-7	3.608e-16	1.899e-8	1.6458e-7	6.752e-7	9.711e-8	1.9941e-7	1.672e-7			
		T	2.842e-8	8.7818e-8	7.044e-8	1.117e-16	1.057e-8	1.0320e-7	1.214e-7	6.568e-8	1.2258e-7	9.46e-8			
		V	6.932e-9	2.1574e-8	1.87e-8	1.013e-17	3.183e-9	2.8567e-8	4.03e-8	1.727e-8	3.4410e-8	2.849e-8			
F-15	MIL	R	5.911e-8	1.8265e-7	1.575e-7	1.114e-15	3.338e-8	2.6097e-7	3.842e-7	1.424e-7	3.2218e-7	2.777e-7			
		T	4.198e-8	1.2972e-7	1.037e-7	4.733e-16	2.176e-8	1.7114e-7	5.895e-7	9.396e-8	2.1113e-7	1.474e-7			
		V	1.113e-8	3.4392e-8	2.879e-8	1.831e-17	4.279e-9	4.2055e-8	2.997e-8	2.687e-8	4.9917e-8	4.152e-8			
F-16	MIL	R	5.958e-8	1.8410e-7	1.542e-7	6.741e-16	2.596e-8	2.3469e-7	4.94e-7	1.425e-7	2.8232e-7	2.078e-7			
		T	4.734e-8	1.4628e-7	1.129e-7	3.875e-16	1.969e-8	1.7392e-7	6.516e-7	1.041e-7	2.1010e-7	1.61e-7			
		V	1.402e-8	4.3322e-8	3.41e-8	7.02e-17	8.379e-9	6.0073e-8	1.531e-8	3.033e-8	7.5446e-8	7.441e-8			
F-4	AB	R	9.018e-8	2.7866e-7	2.386e-7	1.575e-15	3.969e-8	3.6163e-7	2.232e-7	2.207e-7	5.3016e-7	3.548e-7			
		T	7.233e-8	2.2350e-7	1.734e-7	9.312e-16	3.052e-8	2.6800e-7	4.203e-7	1.597e-7	3.2404e-7	2.429e-7			
		V	3.176e-8	9.8138e-8	6.725e-8	4.297e-16	2.073e-8	1.3151e-7	6.187e-7	5.792e-8	1.6956e-7	1.333e-7			
F-15	AB	R	1.762e-7	5.4446e-7	4.561e-7	4.52e-15	6.723e-8	6.6452e-7	1.908e-7	4.259e-7	7.8792e-7	6.354e-7			
		T	8.963e-8	2.7636e-7	2.384e-7	1.51e-15	3.886e-8	3.5886e-7	3.301e-7	2.209e-7	4.3015e-7	3.179e-7			
		V	5.609e-8	1.7332e-7	1.255e-7	1.408e-15	3.752e-8	2.4182e-7	3.418e-7	1.086e-7	3.1068e-7	1.949e-7			
F-16	A:	R	1.771e-7	5.4724e-7	4.602e-7	5.624e-15	7.499e-8	6.9268e-7	1.71e-7	4.265e-7	8.3043e-7	6.54e-7			
		T	9.894e-8	3.0572e-7	2.545e-7	1.654e-15	4.067e-8	3.8058e-7	3.154e-7	2.363e-7	4.5530e-7	3.798e-7			
		V	1.542e-7	4.7648e-7	2.681e-7	9.329e-15	9.659e-8	5.6752e-7	1.328e-7	2.247e-7	7.4482e-7	5.932e-7			
NOISE		R	7.228e-9	2.2333e-8	1.699e-8	1.031e-17	3.211e-9	2.6947e-8	3.994e-8	1.555e-8	3.2841e-8	2.428e-8			
		T	6.161e-9	1.9037e-8	1.341e-8	2.781e-18	1.668e-9	1.8577e-8	7.698e-8	1.266e-8	2.1638e-8	1.798e-8			
		V	4.256e-9	1.3151e-8	9.092e-9	3.329e-18	1.824e-9	1.4748e-8	7.030e-8	8.271e-9	1.8097e-8	1.270e-8			
NOISE		R	3.641e-9	1.1249e-8	8.659e-9	2.262e-18	1.504e-9	1.3321e-8	8.528e-8	7.982e-9	1.6882e-8	1.420e-8			
		T	2.884e-9	8.9114e-9	7.428e-9	2.475e-18	1.573e-9	1.2305e-8	8.153e-8	6.720e-9	1.5193e-8	1.603e-8			
		V	2.279e-9	7.0395e-9	5.410e-9	2.060e-18	1.435e-9	9.8595e-9	6.936e-8	4.764e-9	1.2494e-8	9.656e-9			

Table B3d. Displacement Statistics for Operations in the Fort Smith Hush House; Site 4

(Units of Meters.)

			1.0 SEC PEAK DISTRIBUTION																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																			
			FULL DISTRIBUTION			EXTREME VALUE TYPE I																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																
			RMS	EXCEEDENCE LEVEL	MEAN	VARIANCE	STANDARD DEVIATION	EXCEEDENCE LEVEL	NORMAL	EXCEEDENCE LEVEL																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																												
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NOTE: Components marked with a star had clipped data and approximate statistical functions were used to estimate values.

Table B3e. Displacement Statistics for Operations in the Fort Smith Hush House; Sites 7 and 8

(Units of Meters)

AIRCRAFT	POWER	CHL	RMS	FULL DISTRIBUTION		1.0 SEC PEAK DISTRIBUTION										MAXIMUM OBSERVED
				EXCEEDENCE LEVEL	0.001% EXCEEDENCE	MEAN	VARIANCE	STANDARD DEVIATION	NORMAL		EXTREME VALUE TYPE I					
									0.001% EXCEEDENCE LEVEL	ALPHA	U	EXCEEDENCE LEVEL	U	0.001% EXCEEDENCE LEVEL	PEAK	
F-4	MIL	R	7.570e-9	2.3392e-8	1.608e-8	3.131e-17	5.596e-9	3.3424e-8	2.292e8	1.356e-8	4.3696e-8	3.592e-8	1.356e-8	4.3696e-8	3.592e-8	3.592e-8
		T	1.649e-8	5.0967e-8	3.171e-8	1.741e-16	1.320e-8	7.2615e-8	9.719e7	2.577e-8	9.6837e-8	2.577e-8	9.6837e-8	2.577e-8	8.328e-8	
		V	4.850e-9	1.4986e-8	1.048e-8	9.696e-18	3.114e-9	2.0137e-8	4.119e8	9.083e-9	2.5852e-8	9.083e-9	2.5852e-8	9.083e-9	2.401e-8	
F-15	MIL	R	1.337e-8	4.1319e-8	2.494e-8	1.629e-16	1.276e-8	6.4508e-8	1.005e8	1.919e-8	8.7937e-8	6.944e-8	1.919e-8	8.7937e-8	6.944e-8	6.944e-8
		T	2.367e-8	7.3139e-8	4.504e-8	4.096e-16	2.034e-8	1.0778e-7	5.337e7	3.594e-8	1.4493e-7	3.594e-8	1.4493e-7	3.594e-8	1.069e-7	
		V	4.682e-9	1.4468e-8	1.091e-8	1.158e-17	3.403e-9	2.1456e-8	3.769e8	9.375e-9	2.7703e-8	9.375e-9	2.7703e-8	9.375e-9	1.921e-8	
F-16	MIL	R	1.547e-8	4.7805e-8	3.044e-8	2.001e-16	1.415e-8	7.4233e-8	9.066e7	2.407e-8	1.0026e-7	7.738e-8	2.407e-8	1.0026e-7	7.738e-8	7.738e-8
		T	3.228e-8	9.9743e-8	6.104e-8	1.142e-15	3.379e-8	1.6579e-7	3.796e7	4.583e-8	2.2781e-7	4.583e-8	2.2781e-7	4.583e-8	2.201e-7	
		V	7.042e-9	2.1760e-8	1.502e-8	4.075e-17	6.304e-9	3.4809e-8	2.009e8	1.215e-8	4.6526e-8	1.215e-8	4.6526e-8	1.215e-8	4.253e-8	
F-4	AB	R	1.312e-8	4.0549e-8	2.702e-8	1.431e-16	1.196e-8	6.4104e-8	1.072e8	2.163e-8	8.6064e-8	6.349e-8	2.163e-8	8.6064e-8	6.349e-8	6.349e-8
		T	2.270e-8	7.0131e-8	4.195e-8	5.029e-16	2.242e-8	1.1147e-7	5.720e7	3.186e-8	1.5263e-7	3.186e-8	1.5263e-7	3.186e-8	1.209e-7	
		V	7.249e-9	2.2399e-8	1.729e-8	2.524e-17	5.024e-9	3.2860e-8	2.553e8	1.503e-8	4.2081e-8	1.503e-8	4.2081e-8	1.503e-8	3.274e-8	
F-15	AB	R	1.446e-8	4.4680e-8	3.469e-8	6.778e-17	8.233e-9	6.0209e-8	1.558e8	3.098e-8	7.5321e-8	5.684e-8	3.098e-8	7.5321e-8	5.684e-8	5.684e-8
		T	2.072e-8	6.4022e-8	4.419e-8	3.445e-16	1.856e-8	1.0173e-7	6.902e7	3.583e-8	1.3581e-7	3.583e-8	1.3581e-7	3.583e-8	1.024e-7	
		V	7.688e-9	2.3757e-8	1.999e-8	1.385e-17	3.695e-9	3.1442e-8	3.471e8	1.832e-8	3.8225e-8	1.832e-8	3.8225e-8	1.832e-8	2.911e-8	
F-16	AB	R	1.618e-8	4.9933e-8	3.564e-8	2.328e-16	1.526e-8	8.2943e-8	8.405e7	2.877e-8	1.1095e-7	9.076e-8	2.877e-8	1.1095e-7	9.076e-8	9.076e-8
		T	3.191e-8	9.8597e-8	5.779e-8	1.697e-15	4.120e-8	1.8551e-7	3.113e7	3.925e-8	2.6113e-7	3.925e-8	2.6113e-7	3.925e-8	2.429e-7	
		V	7.743e-9	2.3925e-8	1.984e-8	3.493e-17	5.910e-9	3.8160e-8	2.170e8	1.718e-8	4.9009e-8	1.718e-8	4.9009e-8	1.718e-8	4.356e-8	
NOISE (SITE 7)		R	9.177e-9	2.8358e-8	1.584e-8	7.012e-17	8.374e-9	4.1801e-8	1.532e8	1.207e-8	5.7171e-8	1.207e-8	5.7171e-8	1.207e-8	5.164e-8	5.164e-8
		T	1.767e-8	5.4611e-8	2.980e-8	3.661e-16	1.913e-8	8.9113e-8	6.704e7	2.119e-8	1.2423e-7	2.119e-8	1.2423e-7	2.119e-8	1.155e-7	
		V	4.627e-9	1.4298e-8	8.805e-9	1.732e-17	4.161e-9	2.1705e-8	3.082e8	6.932e-9	2.9343e-8	6.932e-9	2.9343e-8	6.932e-9	2.808e-8	
NOISE (SITE 8)		R	5.638e-9	1.7421e-8	1.362e-8	2.641e-17	5.139e-9	2.9547e-8	2.496e8	1.130e-8	3.8980e-8	1.130e-8	3.8980e-8	1.130e-8	3.777e-8	3.777e-8
		T	9.998e-9	3.0894e-8	2.368e-8	5.805e-17	7.619e-9	4.7297e-8	1.603e8	2.025e-8	6.1282e-8	2.025e-8	6.1282e-8	2.025e-8	4.578e-8	
		V	2.794e-9	8.6327e-9	7.110e-9	5.221e-18	2.2652e-9	1.4193e-8	5.613e8	6.081e-9	1.8387e-8	6.081e-9	1.8387e-8	6.081e-9	1.590e-8	